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A PHYSIOLOGICAL STUDY OF DEVELOPMENT AND RIPENING IN THE STRAWBERRY [1]

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INTRODUCTION

The work reported in this paper constitutes a comparative study of the physiology of development and ripening in a group of varieties of strawberries (*Fragaria* spp.) so selected as to represent the most popular and widely grown commercial varieties of the Atlantic seaboard States. It was begun in 1925 and was continued for 4 years in conjunction with a more extensive study of a larger number of strawberry varieties and strains which was being carried on to determine their suitability for the fresh market and for canning, preserving, freezing, and other methods of preservation. So far as the writers have been able to ascertain, no detailed study of the physiology of development of the strawberry has hitherto been made. Such reports of chemical analyses of the fruit as were found in the literature were concerned with the composition of the mature fruit, and these were few, by far the larger number of the named varieties in general cultivation apparently never having been subjected to analysis for any purpose.

The present work attempts to extend existing knowledge of the physiology of the fruit by outlining the nature of the chemical and physical changes that take place in it during the course of development and ripening. A considerable number of varieties have been employed for purposes of comparison.

REVIEW OF LITERATURE

Trzeciok (*21*)[3] in 1892 reviewed such analytical work on the strawberry as had appeared in the European literature up to that time, and reported the results of his own determinations of total solids, titratable acidity, reducing and total sugars, and ash upon material obtained from wild plants growing in the vicinity of Erlangen, Bavaria. Detailed analyses of the ash of the fruit were made. The sugar and the acid content of the freshly expressed juice were determined, the juice was subjected to fermentation by yeast, and the analysis of the liquid was repeated at intervals during the course of the fermentation. Most of the analyses cited by Trzeciok deal with the wild European strawberry, *Fragaria vesca* L., as do those assembled by König (*16, pp. 776–777*), and in work dealing with cultivated varieties the varietal names are not given.

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[2] The writers desire to express their gratitude to George M. Darrow, senior pomologist, Division of Fruit and Vegetable Crops and Diseases, for permission to use the material employed in this study and for many courtesies in the course of the work.

[3] Reference is made by number (italic) to Literature Cited, p. 695.

A number of earlier American workers have reported the results of analyses made primarily for the purpose of comparing the nutritive value of the strawberry with that of other fruits. Stone (*20*) made analyses of 20 varieties of ripe strawberries grown at the Tennessee Agricultural Experiment Station in 1889, the determinations including total solids by drying at 105° C., reducing and total sugars, acidity as malic acid, crude fiber, crude protein, ether extract, and nonnitrogenous extract. Shaw (*18*) made analyses of 9 varieties grown at the Oregon Agricultural Experiment Station in 1898 and 1899, and compared the averaged results with those reported by Stone and with those for European varieties assembled by König. Shaw reached the conclusion that the European varieties are somewhat higher in sugar and acid and in insoluble and total solids than American berries, but are lower in protein. The comparison would appear to be essentially a comparison of the European *Fragaria vesca* with the American *F. virginiana* Duchesne, with or without hybridization with other species. Weber (*23*) made determinations of acid and sugar content upon 2 varieties, one an unnamed seedling, at the Ohio Agricultural Experiment Station in 1887. Of all the varieties named by these workers, not more than two or three are now being propagated by nurserymen and none is important commercially.

The only recent work approximating a comparative study of the chemistry of a group of varieties is that of Vercier (*22*), which was concerned primarily with the determination of the effect of domestication and hybridization in altering size and composition of the fruit. Vercier grew 15 cultivated varieties and strains of strawberries under identical conditions together with the wild *Fragaria vesca* and made determinations of weight per berry; percentage of dry matter, sugar, and acid in the fruit; and yield of juice. As compared with the wild species, the cultivated strains were 600 to 1,800 percent higher in average weight per berry, but were markedly lower in total solids and sugars, and in most cases somewhat lower in titratable acidity. Vercier concluded that the trend of selection and breeding had been toward increase in size of fruits at the expense of the solids content and food value of the fruit. Gimingham (*12*) grew 2 varieties of strawberries, Epicure and Royal Sovereign, on 5 types of soil, continuing the work over 3 years and determining percentages of sugar and acid in the fruit. He concluded that each variety has a definite standard of composition that is affected in only a very limited degree by the character of the soil on which the berry is grown. Royal Sovereign was consistently higher in sugar content and lower in titratable acidity than Epicure on all soils and in all seasons. In the degree of influence exerted upon sugar content, seasonal conditions were predominant over all other factors.

Studies of the effects of cultural treatments or fertilizer applications upon growth and productiveness of the strawberry plant are rather numerous but rarely include analytical data upon the fruit. The work of Shoemaker and Grove (*19*) presents an exception. These authors determined the effects of rather heavy spring applications of a nitrogenous fertilizer on the fruit of only one variety, namely, Howard 17 (Premier). The fruit from the heavily fertilized plots was slightly less firm as determined by resistance to pressure tests, was consistently higher in total nitrogen (including nitrates, which were

not separately determined), higher in catalase activity, lower in actual acidity and in reducing sugar, and generally lower in total sugars than that from the check plots. There were no consistent differences in moisture content or in ability of the fruit to withstand handling and shipment. Kimbrough (*15*), working at the Alabama Agricultural Experiment Station, found that weather conditions, especially rainfall, had a decidedly greater effect upon the composition of strawberries of the Missionary [4] variety than did fertilizer treatments. He determined the moisture and sugar content of berries from the various fertilizer plots at intervals of a few days throughout the bearing season. The amount of rainfall for 3 to 6 days prior to picking determined the composition, as berries from all plots had high moisture content and low sugar content after rainfall, and the reverse condition after a period of no precipitation. In a practically rainless fruiting season, fruit from all plots artificially watered was uniformly softer in texture than that from unwatered plots. Cochran and Webster (*4*) made analyses of berries of the variety Aroma [5] at the Oklahoma Agricultural Experiment Station from 12 plots that had received various fertilizer treatments, but were unable to find consistent correlations between composition and firmness or between either of these factors and fertilizer treatments. Loree (*17*) made detailed analyses of nitrogen, carbohydrate, and mineral content of roots and tops of Dunlap strawberry plants after the application of various fertilizer combinations, but confined his analytical work on the fruit to determination of moisture content. A number of workers have reported results of determinations of the nutritive value of the strawberry or of examination of the fruit for the presence or absence of some particular constituent, but review of work of this character is not pertinent to the present purpose.

MATERIAL AND METHODS

The material employed in the study was grown at the United States Plant Field Station at Glenn Dale, Md., and formed a part of the variety collection assembled in connection with the strawberry-breeding work conducted by George M. Darrow. The Glenn Dale station is located 15 miles northeast of Washington, D. C. The soil formation is classified as Collington sandy loam, the particular area occupied by the strawberry plantings being a decidedly sandy loam. Rearrangement of the plantings at the station in 1927 necessitated the transfer of the variety collection to another area, but the conditions in the new location were not materially different from those in the old. The samples taken in 1928 were obtained from this planting.

Twelve varieties, namely, Missionary, Howard 17 (Premier), Klondike, Parsons (Gibson), New York, Dunlap, Sample, Aroma, Gandy, Chesapeake, Progressive, and Portia, were employed in the study. The first 9 are the most widely grown commercial varieties, and together made up more than 80 percent of the commercial acreage of the United States at the time the work was begun (*8, p. 308*). Chesapeake is of considerable commercial importance in Maryland and adjacent territory, Progressive is one of the most widely grown everbearing strawberries, and Portia is a canning variety of relatively

[4] Name of variety was supplied by Dr. Kimbrough in a personal communication.
[5] Name of variety supplied by Professor Cochran in a personal communication.

restricted cultivation that has shown promise of value. Collectively, the group was believed to be as truly representative of the commercially important strawberries of the country as it is possible for material grown at any one location to be.

The general plan followed in obtaining material for analysis was to make collections of fruit at intervals of 5 to 7 days during the period of development and ripening. This method of sampling secured from each variety in every year two fairly complete series of fruits, one developed from the earlier, the other from the later blooms. The first collection was generally made as soon after blooms had set as sufficient material could be obtained, and usually consisted of berries that were just dropping the petals but which differed considerably in size. These for the most part had developed from the first flowers to open on the plants. Upon arrival at the laboratory, the berries were graded into 2 or 3 lots on the basis of size, if the quantity of available material and the range in size of fruit permitted such separation. It was originally intended to begin the sampling of any variety as soon as the plants had set sufficient fruit to yield representative samples, but this was found to be impracticable. The list of varieties includes early, midseason, and late-blooming, but the actual sequence of flowering varied greatly from year to year. As the distance from the laboratory precluded the making of collections with sufficient frequency to secure individual varieties at any desired stage, the method adopted was that of beginning sampling as soon as a majority of the varieties had set sufficient fruit. Consequently the initial samples varied somewhat in size and stage of development from year to year.

The second sampling was usually made approximately a week after the first. At that time an attempt was made to collect material representative of all the fruit on the plants, large and small. This material was subsequently divided into two or three lots on the basis of size, and a similar method was followed at subsequent samplings. In consequence the smallest fruits collected at the second or third sampling more or less closely approximated in size and stage of development the largest fruits taken at the first sampling. Similar duplications occurred throughout, so that the season's samples were made up of two or three series which succeeded one another in development on the plants and collectively constituted a series of cross sections at various stages of development of the crop borne by the plants in that year. As the fruit became full-grown and ripening set in, the material was divided on the basis of color, as green, whitened, reddened, and ripe, without reference to size.

This method of sampling affords no information as to the exact age of the fruits making up any particular sample. At the time the plants were flowering it was not feasible to tag flowers at opening so that the exact age of fruits could be known; consequently it was necessary to rely on the size and color of the fruit as a means of grading it roughly into lots of approximately equal age. For determining stages of maturity only slightly differing one from another it was necessary to rely upon the puncture tests.

The firmness, or resistance of the fruit to puncture, was determined as soon as the fruit reached the laboratory. The pressure tester described by Culpepper and Magoon (*6*) was used, with a needle 0.032

inch in diameter and a scale graduated in 5-g intervals. Twenty to thirty berries were used in a test, each being tested at 2 to 4 points, midway from stem to tip, at the tip, and near the attachment to the stem. The values given in table 1 under the heading "Puncture tests" are averages of all the readings obtained from the individual tests made upon the sample.

The instrument employed for measuring the firmness of the fruit was not ideal in every respect. It does not give a measure of the resistance of the fruit to deformation or flattening as does the pressure or "squeeze" tester developed by Haller, Harding, and Rose (*13*) subsequent to the completion of this work. It measures only the resistance of the tissues to penetration by a small needle. As shown later, this type of tester gives an index of maturity which is quite dependable, but it does not bring out varietal differences in firmness or resistance to crushing in shipping or handling.

Determinations of hydrion concentration were made, in 1927 and 1928 only, on a portion of the fresh sample. The berries were finely ground in a mortar and the juice was expressed by hand through triple layers of muslin. Duplicate or triplicate determinations, agreeing to within 0.05 pH, were made by means of the Bailey hydrogen electrode. A quinhydrone electrode was employed as a comparison electrode. In some cases scarcity of material necessitated the use of a micro-electrode (*2*). In these instances, a number of agreeing determinations were always secured.

Samples for chemical analysis were made in duplicate and were preserved by slicing into a tared beaker a sufficient number of berries to give the desired weight (50 or 100 g), transferring them to a storage container, adding sufficient 95 percent alcohol to make the final concentration 80 to 85 percent, heating to boiling, sealing, and storing in the laboratory until the analyses were begun, usually after an interval of 6 to 8 months. At that time extraction was completed with fresh 95-percent alcohol in a Soxhlet extractor, the extract made up to volume, and aliquots taken for the several determinations, which were made according to the official methods of the Association of Official Agricultural Chemists (*1*).

ANALYTICAL DATA

The analytical data are presented in table 1. In the examination of these data the purpose will be (1) to trace in general outline the character of the changes in composition occurring in the fruit in the course of its development, regardless of variety or year; and (2) to determine the extent to which a variety has definable chemical individuality which persists from season to season despite variations in seasonal conditions and other varying factors and which consequently characterizes the variety as a chemical and physical entity. The data should indicate the extent to which the course of these changes may be modified by the environmental conditions prevailing in the plots during the development of the fruit, but since detailed records of these conditions were not kept, a discussion of this phase of the subject is not attempted.

TABLE 1.—*Chemical composition and resistance to puncture of strawberry varieties during development and ripening*

AROMA

Date	Diameter	Description	Sugar			Titratable acidity	Astringency			Solids			Puncture test	pH
			Reducing	Cane	Total		Total	Tannin	Nontannin	Soluble	Insoluble	Total		
1925	*Mm*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Grams*	
May 13	5–8		1.70	0.32	2.02	0.659	2.179	1.504	0.675	5.30	8.30	13.60	378	
Do	8–12		2.29	.24	2.53	.906	1.248	.735	.513	4.96	7.34	12.30	354	
May 19	9–15		1.98	.02	2.00	.688	.695	.201	.494	5.66	7.37	13.03	330	
Do	15–21	Large red	2.44	.18	2.62	.771	.575	.368	.207	5.29	5.89	11.18	263	
May 26		Green, reddened	2.23	.70	2.93	.640	.436	.248	.188	5.06	4.54	9.60	213	
Do		Medium red	2.60	.62	3.22	.569	.332	.155	.177	5.20	3.67	8.87	110	
Do		Red ripe	3.29	.25	3.54	.480	.334	.116	.218	5.64	3.50	9.14	80	
June 5		Very soft	4.68	.30	4.98	.439	.347	.183	.164	6.03	3.38	9.41	12	
1926														
May 27	8–11	Small	2.00	.54	2.54	.735	1.526	1.144	.382	5.96	9.40	15.36	356	
Do	11–15	Medium	2.32	.65	2.97	.796	1.348	.895	.453	5.88	7.54	13.42	302	
Do	12–18	Large	2.90	.18	3.08	.909	.988	.761	.227	5.82	7.27	13.09	215	
June 3	18–29	Green	3.38	.51	3.89	.724	.429	.284	.145	5.77	6.73	12.50	39	
Do	24–32	Medium	3.73	.65	4.38	.706	.392	.235	.157	6.14	3.55	9.69	32	
Do	24–35	Ripe	4.68	.46	5.14	.679	.563	.469	.094	7.18	3.43	10.61	16	
June 11	24–35	Full ripe	4.51	.66	5.17	.559	.300	.132	.168	6.68	3.02	9.70	15	
1927														
June 3	18–27	5 percent red	2.59	.36	2.95	.990	.438	.260	.178	5.28	5.13	10.41	101	
Do	18–27	75 percent red	2.56	.84	3.40	.990	.400	.250	.150	5.52	4.09	9.61	61	
Do	18–27	Firm ripe	3.52	.84	4.36	.811	.280	.114	.166	6.88	3.11	9.99	39	

CHESAPEAKE

1925														
May 13	6–12		1.80	1.15	2.95	0.972	3.662	1.796	1.866	6.30	10.34	16.64	437	
Do	9–15		1.97	.45	2.42	.974	2.048	.824	1.224	5.21	8.11	13.32	389	
May 19	6–12		2.01	.51	2.52	1.376	2.726	1.205	1.521	5.92	8.36	14.28	381	
Do	9–15		2.76	.42	3.18	.903	1.325	1.081	.244	5.62	6.81	12.43	354	
May 26		Green, reddened	3.31	.63	3.94	.685	.394	.218	.176	6.08	4.43	10.51	151	
Do		Red ripe	3.82	.89	4.71	.671	.297	.161	.136	6.52	3.61	10.13	69	
June 5		Ripe	5.38	.19	5.57	.573	.363	.188	.175	6.46	3.37	9.83	15	

1926														
May 27	8–14	Small	1.56	1.17	2.73	.691	1.611	1.093	.518	6.16	8.44	14.60	333	
Do	14–20	Medium	2.87	.72	3.59	.738	1.391	1.183	.208	6.29	7.63	13.92	297	
Do	17–24	Large	3.01	.54	3.55	.666	1.090	.840	.250	6.28	6.76	13.04	229	
June 3	21–23	Greenish red	4.77	.49	5.26	.964	.481	.295	.186	7.68	4.32	12.00	33	
Do	21–35	Ripe	5.23	1.20	6.43	.800	.401	.249	.152	8.42	3.60	12.02	23	
June 11	21–35	Full ripe	5.86	.32	6.18	.618	.322	.209	.113	8.00	3.15	11.15	18	
1927														
May 20	12–18	Green	2.03	.63	2.66	.745	1.090	.760	.330	5.24	7.58	12.82	304	
May 28	12–18	Small green	1.86	.31	2.17	.938	.810	.516	.294	5.08	7.98	13.06	264	
Do	21–30	Large green	2.51	1.05	3.56	1.072	.470	.270	.200	5.76	5.47	11.23	211	
June 3	18–27	Green	2.66	.72	3.38	1.340	.550	.374	.176	6.56	5.64	12.20	143	
Do	18–30	10 percent pale red	3.22	.80	4.02	1.210	.380	.220	.160	6.88	4.40	11.28	98	
Do	18–30	50 percent pale red	3.24	1.23	4.47	1.185	.376	.232	.144	7.52	3.75	11.27	57	
Do	18–30	Firm ripe	4.31	1.27	5.58	.948	.272	.142	.130	7.40	3.35	10.75	33	
1928														
May 17	6–11		1.73	1.40	3.13	1.166	2.760			7.47	11.63	19.10	336	4.47
May 29	15–18	Still green	2.24	.57	2.81	.948	.886			5.44	6.93	12.37	218	3.55
June 11	8–12	Some red	3.26	2.74	6.00	1.090	.342			6.72	3.77	10.49	56	3.10
Do		Ripe	4.72	1.99	6.71	.944	.296			8.46	3.25	11.71	26	3.27
Do		Dead ripe	5.09	.90	5.99	.662	.270			8.04	2.90	10.94	12	3.51

DUNLAP

1925														
May 5	6–11		1.18	0.78	1.96	1.335	3.253	1.586	1.667	5.80	9.91	15.71	378	
Do	9–14		1.62	.83	2.45	1.762	2.125	1.254	.871	5.38	9.13	14.51	365	
May 13	6–11		1.99	.02	2.01	.833	1.033	.634	.399	4.50	8.15	12.65	330	
Do	9–15		1.78	.34	2.12	.875	.638	.333	.305	4.61	6.86	11.47	266	
May 19	9–15		1.84	.47	2.31	1.085	.505	.339	.166	5.00	5.88	10.88	233	
Do	12–21	Faint red, whitened	2.38	.50	2.88	.917	.320	.105	.215	3.94	4.64	8.58	132	
Do	18–24	Red ripe	3.15	.77	3.92	.912	.475	.353	.122	6.37	3.95	10.32	49	
May 26		Green, reddened	2.49	.25	2.74	.820	.381	.172	.209	4.95	4.44	9.39	67	
Do		Red ripe	3.00	.29	3.29	.725	.267	.103	.164	5.60	4.06	9.66	48	
June 6		Very ripe	4.19	.60	4.79	.560	.332	.132	.200	6.27	4.33	10.60		
1926														
May 27	14–21	Green	2.48	.33	2.81	.960	.572	.352	.220	5.46	6.81	12.27	154	
Do	15–27	Medium	3.66	.57	4.23	.948	.421	.319	.102	6.18	5.57	11.75	86	
Do	18–27	Ripe								6.80	4.37	11.17	19	
June 3	18–27	Greenish red	3.58	.64	4.22	.888	.341	.202	.139	5.65	4.05	9.70	25	
Do	18–33	Medium	3.72	.42	4.14	.783	.297	.177	.120	6.26	3.83	10.09	12	
Do	18–33	Ripe	4.31	1.09	5.40	.742	.320	.197	.123	6.32	3.56	9.88	7	
June 10	18–33	Full ripe	3.57	.84	4.41	.530	.319	.170	.149	7.84	3.83	11.67		

TABLE 1.—*Chemical composition and resistance to puncture of strawberry varieties during development and ripening*—Continued

DUNLAP—Continued

Date	Diameter	Description	Sugar			Titratable acidity	Astringency			Solids			Puncture test	pH
			Reducing	Cane	Total		Total	Tannin	Nontannin	Soluble	Insoluble	Total		
1927	*Mm*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Grams*	
May 12	11-14	Green	1.25	.23	1.48	.910	1.070	.652	.418	4.48	8.79	13.27	341	3.68
May 20	11-14	Small	1.13	.39	1.52	.983	.740	.476	.264	4.08	8.15	12.23	276	
Do	12-15	Medium	1.41	.35	1.76	.942	.510	.300	.210	4.04	7.28	11.32	256	3.57
Do	15-20	Large	1.54	.12	1.66	1.050	.482	.276	.206	4.20	6.83	11.03	220	
May 28	18-24	White	1.92	.37	2.29	1.082	.378	.230	.148	4.76	4.92	9.48	89	3.35
Do	18-27	25 percent pale red	2.28	.30	2.58	1.030	.274	.148	.126	4.76	3.94	8.70	51	
Do	18-27	Fairly deep red	3.22	.46	3.68	.942	.290	.210	.080	5.72	3.69	9.41	19	3.43
June 3	18-27	Dead ripe	3.32	1.10	4.42	.740	.254	.128	.126	6.20	3.08	9.28	25	3.34
			GANDY											
1925														
May 13	5-8		2.09	0.20	2.29	1.280	4.109	2.507	1.602	7.13	11.21	18.34	439	
Do	6-12		2.10	.52	2.62	1.036	2.500	1.140	1.360	5.12	7.88	13.00	423	
May 19	9-15		1.58	.56	2.14	1.247	2.512	1.143	1.369	5.37	8.54	13.91	410	
Do	12-21		2.06	.51	2.57	1.583	1.998	.890	1.108	5.27	8.37	13.64	372	
May 26		Green	2.65	.34	2.99	.760	.569	.210	.359	5.36	5.91	11.27	297	
Do		Red ripe	3.45	.45	3.90	.845	.418	.242	.176	6.69	4.49	11.18	158	
June 4		Medium firm	4.85	.58	5.43	.744	.382	.188	.194	7.07	3.74	10.81	25	
1926														
May 27	8-14	Small	2.59	.20	2.79	.845	1.752	1.476	.276	6.37	10.11	16.48	330	
Do	14-20	Large	2.60	2.38	4.98	.917	1.430			6.68	8.97	15.65	317	
June 3	18-30	White	3.48	.22	3.70	1.271	.915	.711	.204	7.00	6.41	13.41	131	
June 11	18-30	Full ripe	6.39	.84	7.23	.840	.433	.225	.208	9.30	3.58	12.88	15	
1927														
May 28	11-18	Small	1.51	.59	2.10	1.257	1.140	.740	.400	5.76	10.45	16.21	335	
Do	17-24	Medium	2.00	.47	2.47	1.268	.842	.604	.238	5.80	8.56	14.36	285	
Do	21-27	Large	2.26	.64	2.90	1.327	.666	.484	.182	5.80	6.77	12.57	218	
June 3	18-30	White	3.13	1.07	4.20	1.020	.480	.334	.146	6.92	5.29	12.21	107	
Do	24-36	75 percent red	4.06	1.27	5.33	1.525	.362	.222	.140	8.12	3.98	12.10	51	
Do	27-36	Firm ripe	4.56	1.79	6.35	1.331	.338	.218	.120	8.68	3.53	12.21	26	

HOWARD 17 (PREMIER)

1925														
Apr. 28	6–9					1.236	3.396	2.741	0.655	5.17	8.59	13.76	317	
Do	9–12					1.259	2.044	1.359	.685	4.53	7.50	12.03	321	
May 13	5–9		1.97	0.30	2.27	.765	1.842	1.293	.549	5.12	7.64	12.76	301	
Do	9–15		1.83	.75	2.58	.582	.700	.357	.343	4.67	5.58	10.25	258	
Do	15–24		2.02	.57	2.59	.800	.645	.510	.135	4.69	4.34	9.03	194	
May 19	15–27	Green	2.98	.20	3.18	.747	.426	.240	.186	5.33	3.88	9.21	163	
Do	18–30	Medium	3.14	.68	3.82	.777	.253	.070	.183	6.38	3.37	9.75	71	
Do	18–30	Red ripe	4.31	.86	5.17	.581	.218	.060	.158	7.42	3.03	10.45	37	
May 26		Green	3.45	.46	3.91	.724	.214	.051	.163	6.34	2.64	8.98	39	
Do		Ripe	4.27	.94	5.21	.635	.223	.083	.140	7.46	2.49	9.95	23	
1926														
May 21	8–11	Small	1.76	.82	2.58	.695	1.558	1.155	.403	5.69	7.08	12.77	250	
Do	12–15	Medium	1.94	.43	2.37	.761	1.082	.578	.504	5.35	6.82	12.17	179	
Do	17–23	Large	2.45	.23	2.68	.876	1.037	.591	.446	5.46	6.27	11.73	158	
May 27	15–30	Green	2.47	.98	3.45	.855	.561	.464	.097	5.94	4.53	10.47	125	
Do	20–30	Medium	3.63	.54	4.17	.957	.452	.279	.173	6.32	4.11	10.43	95	
Do	18–31	Ripe	3.86	.84	4.70	.872	.360	.270	.090	7.01	3.54	10.55	31	
June 3	14–21	Green	3.42	.65	4.27	.885	.234	.120	.114	6.15			27	
Do	20–26	Medium	3.96	.55	4.51	.855	.310	.185	.125	6.56	3.08	9.64	11	
Do	24–36	Ripe	5.08	1.01	6.09	.701	.298	.219	.079	8.00	2.70	10.70	4	
June 8	24–36	do	3.68	.98	4.66	.512	.293	.201	.092	6.04	2.55	8.59	10	
1927														
May 12	11–14	Green	1.80	.38	2.18	.864	1.294	.924	.370	5.00	6.64	11.64	330	3.98
May 20	14–20	Small	1.92	.51	2.43	.840	.620	.390	.230	4.64	5.35	9.99	199	3.31
Do	17–21	Large	2.40	.50	2.90	.864	.480	.304	.176	5.00	4.66	9.66	188	3.20
May 28	24–30	40 percent pale red	2.79	.71	3.50	.920	.340	.210	.130	5.60	3.08	8.68	59	3.18
Do	24–30	75 percent pale red	3.06	.69	3.75	.918	.260	.170	.090	5.80	2.89	8.69	48	
Do	24–30	100 percent pale red	3.52	.84	4.36	.945	.274	.162	.112	6.56	3.09	9.65	36	3.15
June 3	18–24	do	3.66	1.20	4.86	1.050	.370	.180	.170	6.44	3.25	9.69	52	
Do	24–30	Firm ripe	4.10	1.48	5.58	.930	.280	.160	.120	8.20	2.77	10.97	33	
Do	24–30	Ripe	4.08	1.30	5.38	.726	.262	.152	.110	7.04	2.80	9.84	24	3.36
1928														
May 17	6–11		1.59	.57	2.16	.793	2.661	1.841	.820	6.60	9.18	15.78	316	4.37
Do	9–12		1.54	.71	2.25	.747	1.657	1.085	.572	5.80	7.97	13.77	303	3.95
Do	12–18		1.70	.88	2.58	.747	1.205	.831	.374	5.36	7.33	12.69	219	3.71
May 29	18–30	Nearly white	2.09	1.23	3.32	.873	.517			5.44	4.52	9.96	131	3.23
Do	18–30	Tinge of red	2.59	1.22	3.81	.845	.324	.262	.062	5.80	3.41	9.21	77	3.13
Do	24–30	One-third red	2.91	1.30	4.21	.825	.317	.238	.079	6.12	3.16	9.28	53	3.21
Do	24–30	Nearly all red	3.18	1.64	4.82	.801	.321	.239	.082	6.52	3.05	9.57	29	3.14
June 11	24–30	Dead ripe	3.57	1.54	5.11	.745	.279	.213	.066	6.34	3.63	9.97	27	3.06

TABLE 1.—*Chemical composition and resistance to puncture of strawberry varieties during development and ripening*—Continued

KLONDIKE

Date	Diameter	Description	Sugar			Titratable acidity	Astringency			Solids			Puncture test	pH
			Reducing	Cane	Total		Total	Tannin	Nontannin	Soluble	Insoluble	Total		
1925	*Mm*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Grams*	
Apr. 28	3–9					1.227	3.398	2.268	1.130	5.25	10.47	15.72	397	
Do	6–12					1.939	3.218	2.136	1.082	6.37	12.21	18.58	450	
May 5	6–11					1.518	2.558	1.778	.780	5.30	10.12	15.42	419	
Do	9–15					1.980	2.921	2.488	.433	5.51	7.83	13.34	403	
May 13	9–14		1.51	0.17	1.68	.940	1.251	.734	.517	5.01	8.59	13.60	381	
Do	12–17		2.08	.32	2.40	.804	.566	.223	.343	5.12	6.16	11.28	315	
May 19	12–21	Green	2.97	.00	2.97	.981	.424	.152	.272	5.88	5.01	10.89	198	
Do	18–24	Medium	3.13	.45	3.58	.819	.438	.229	.209	6.44	3.46	9.90	77	
Do	18–27	Ripe	3.99	.55	4.54	1.027	.353	.216	.137	7.05	3.11	10.16	23	
May 26		Very ripe	5.57	.51	6.08	.672	.373	.163	.210	7.70	3.19	10.89	15	
1926														
May 21	6–11	Small	1.43	.63	2.06	1.105	2.116	1.348	.768	6.26	10.33	16.59	374	
Do	11–14	Medium	2.91	.00	2.91	.946	1.391	.950	.441	5.96	9.12	15.08	280	
Do	15–20	Large	2.78	.16	2.94	1.123	1.002	.579	.423	5.85	7.55	13.40	171	
May 27	14–21	Green											162	
Do	20–24	Medium	3.60	1.03	4.63	1.164	.560	.428	.132	7.16	4.54	11.70	97	
Do	20–24	Ripe	4.52	.17	4.69	1.060	.477	.370	.107	7.44	3.52	10.96	44	
June 3	18–24	Greenish red	3.29	.83	4.12	1.179	.443	.345	.098	6.70			46	
Do	18–27	Medium	2.98	.84	3.82	.778	.332	.245	.087	5.10			25	
Do	18–30	Ripe	4.77	.80	5.57	.859	.347	.264	.083	7.58	2.98	10.56	11	
June 8	18–30	Full ripe	4.76	.38	5.14	.790	.293	.143	.150	7.52	2.89	10.41	13	
1927														
May 28	15–21	Tinge of red	2.28	.30	2.58	1.495	.360	.146	.214	5.88	5.58	11.46	110	
Do	15–21	80 percent red	3.04	.69	3.73	1.490	.430	.304	.126	6.48	4.25	10.73	58	
Do	15–21	Deep red	3.26	.70	3.96	1.410	.424	.270	.154	6.92	3.90	10.82	27	

MISSIONARY

1925													
Apr. 28	3–9		0.67	1.07	1.74	1.342	3.922	2.628	1.294	5.37	10.31	15.68	372
Do	6–12		2.07	.35	2.42	1.254	4.050	2.788	1.262	5.86	9.42	15.28	343
May 13	9–12		1.58	.87	2.45	1.269	2.453	1.801	.652	5.56	9.00	14.56	395
Do	9–18		2.27	.15	2.42	.847	.937	.585	.352	5.36	6.68	12.04	320
Do	15–21	Slightly red	3.20	.71	3.91	1.000	.803	.574	.229	6.45	4.20	10.65	287
May 19	6–15		2.00	.42	2.42	1.040	1.221	.634	.587	5.52	5.09	10.61	241
Do	18–30		3.41	.54	3.95	.935	.345	.132	.213	6.74	3.70	10.44	116
Do	18–30	Ripe	4.27	.82	5.09	.760	.269	.055	.204	7.54	4.27	11.81	34
May 26		Very ripe	5.01	.72	5.73	.508	.404	.179	.225	7.13	3.46	10.59	20
1926													
May 21	6–12	Small	1.81	.82	2.63	.940	2.002	1.071	.931	6.05	8.93	14.98	339
Do	11–15	Medium											337
Do	15–21	Large	2.36	1.38	3.74	.982	1.192	.862	.330	5.73	6.59	12.32	230
May 27	14–15	Green	2.85	.69	3.54	.674	.748	.462	.286	5.84	5.62	11.46	196
Do	21–27	Medium	3.43	.81	4.24	.832	.588	.422	.166	6.88	4.16	11.04	66
Do	24–33	Ripe	4.30	.36	4.66	.852	.555	.421	.134	6.75	3.46	10.21	35
June 3	17–27	Green	2.97	.53	3.50	.953	.523	.365	.158	5.69	3.93	9.62	39
Do	18–30	Medium	3.57	.34	3.91	.954	.402	.237	.165	6.10	3.42	9.52	24
Do	18–30	Ripe	4.56	.41	4.97	.685	.379	.217	.162	6.94	3.05	9.99	12
1927													
May 28	3–9		1.54	.16	1.70	1.123	1.194	.729	.465	4.98	10.55	15.53	338
Do	9–18	Green	1.41	.41	1.82	1.250	.780	.504	.276	4.96	7.75	12.71	288
Do	12–21	White [1]	1.88	.54	2.42	1.322	.570	.360	.210	5.36	5.91	11.27	161
June 3	12–24	10 percent pale red	2.57	.19	2.76	1.297	.476	.343	.133	5.24	4.82	10.06	128
Do		Ripe	2.95	.45	3.40	1.285	.420	.290	.130	6.16	4.14	10.30	69
Do		do	5.22	.62	5.84	1.048	.340	.208	.132	8.24	3.59	11.83	27

NEW YORK

1925													
May 5	8–11		1.66	0.51	2.17	1.610	3.667	1.971	1.696	5.31	8.97	14.28	446
Do	11–14		3.31	.84	4.15	1.033	2.128	1.308	.820	5.37	9.06	14.43	403
May 13	6–15		2.38	.21	2.59	.601	1.239	.793	.446	5.63	8.13	13.76	382
Do	12–18		2.25	.60	2.85	.817	.744	.520	.224	5.20	6.49	11.69	313
May 19	12–24		2.77	.20	2.97	.795	.345	.096	.279	5.82	5.45	11.27	212
Do		Red ripe	3.64	.56	4.20	.933	.394	.264	.130	6.89	4.10	10.99	97
May 26		Green, reddened	4.25	1.01	5.25	.650	.292	.145	.147	7.62	3.57	11.13	45
Do		Ripe	4.72	1.34	6.06	.611	.274	.125	.149	8.62	3.23	11.85	25
June 4		Very soft	6.76	1.03	7.79	.552	.276	.116	.160	9.02	3.43	12.45	10

[1] Tinge of red on a few.

TABLE 1.—*Chemical composition and resistance to puncture of strawberry varieties during development and ripening*—Continued

NEW YORK—Continued

Date	Diameter	Description	Sugar			Titratable acidity	Astringency			Solids			Puncture test	pH
			Reducing	Cane	Total		Total	Tannin	Nontannin	Soluble	Insoluble	Total		
1926	*Mm*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Grams*	
May 21	8–15	Small	1.79	.60	2.39	.958	2.016	1.545	.471	6.17	12.68	18.85	429	
Do	18–24	Large	2.03	.76	2.79	.830	1.254	.682	.572	5.62	9.33	14.95	350	
May 27	14–17	Small	2.61	.51	3.12	.972	.765	.534	.231	5.72	7.35	13.07	211	
Do	18–39	Medium	3.15	.41	3.56	.874	.728	.537	.191	6.25	6.50	12.75	204	
Do	21–38	Large	4.03	.70	4.73	.849	.628	.463	.165	6.98	5.48	12.46	138	
June 3	42	Green	4.38	.41	4.79	1.027	.387	.209	.178	7.18	4.15	11.33	56	
Do	24–48	Underripe	5.96	1.34	7.30	.706	.310	.174	.136	8.76	3.62	12.38	16	
June 10	24–48	Full ripe	4.75	.69	5.44	.658	.300	.102	.198	7.54	2.39	9.93	10	
1928														
May 17	5–9		1.75	1.45	3.20	1.040	2.440			6.40	16.52	22.92	400	4.31
Do	8–12		1.72	1.08	2.80	.928	1.708			6.00	10.68	16.68	380	4.02
May 29	17–23	No white	2.14	.80	2.94	1.000	.482			5.32	6.33	11.65	176	3.39
Do	20–30	Some white	2.82	.76	3.58	1.390	.352			6.08	5.19	11.27	142	3.24
June 11	20–30	Ripe	4.80	1.26	6.06	.755	.217			8.38	3.30	11.68	16	3.37
						PARSONS								
1925														
May 5	5–6		1.70	0.57	2.27	0.989	4.275	3.370	0.905	6.17	10.55	16.72	420	
Do	8–12		2.29	.80	3.09	1.157	3.131	2.224	.907	6.00	8.38	14.38	386	
May 13	8–11		1.67	.45	2.12	.806	2.293	1.747	.546	5.14	8.24	13.38	372	
Do	9–15		1.73	.44	2.17	1.523	1.807	.693	1.114	4.79	6.67	11.46	295	
May 19	9–15		1.99	.17	2.16	1.012	1.083	.853	.230	4.95	6.49	11.44	265	
Do	18–24		2.10	.28	2.38	.887	.488	.271	.217	5.08	5.20	10.28	202	
May 26		Green, reddened	2.68	.62	3.30	.694	.381	.204	.177	5.68	3.82	9.50	61	
Do		Red ripe	3.02	.53	3.55	.714	.350	.172	.178	5.82	3.18	9.00	40	
June 5		Very soft	4.61	.44	5.05	.533	.350	.158	.192	6.36	3.32	9.68	18	
1926														
May 21	5–8	Small	2.35	.74	3.09	.829	2.130	1.252	.878	6.14	9.15	15.29	400	
Do	8–9	Large	2.62	.25	2.87	.852	1.550	.977	.573	5.63	8.07	13.70	310	
May 27	15–21	Small	4.46	.51	4.97	1.026	1.158	.992	.166	5.78	7.36	13.14	253	
Do	12–26	Large	2.85	.48	3.33	1.711	.738	.503	.235	5.81	6.17	11.98	194	
June 3	32	Medium	3.68	.71	4.39	1.270	.413	.238	.175	6.44	4.08	10.52	26	
Do	32	Ripe	4.39	.69	5.08	.738	.428	.332	.096	6.76	3.13	9.89	19	

1927													
June 3	12–18	Green	1.64	1.18	2.82	1.216	.621	.374	.247	6.32	4.67	10.99	151
Do	15–21	20 percent red	2.30	.86	3.16	1.145	.370	.216	.154	5.08	3.95	9.03	63
Do	12–24	Red	2.26	.64	2.90	.983	.520	.386	.134	4.80	3.30	8.10	40
Do	21–30	Firm ripe	3.09	1.19	4.28	.773	.290	.150	.140	5.72	2.88	8.60	18

PORTIA

1925													
May 5	6–9		2.17	1.08	3.25	1.855	5.406	3.858	1.548	6.29	10.72	17.01	405
Do	8–14		1.90	.92	2.82	1.082	2.598	1.565	1.033	5.57	9.46	15.03	359
May 13	6–9		1.69	.24	1.93	.606	1.373	.827	.546	4.53	8.53	13.06	339
Do	12–15		2.29	.31	2.60	1.221	.763	.360	.403	4.49	7.48	11.97	316
May 19	12–18		2.10	.36	2.46	.719	.876	.593	.283	4.73	7.15	11.88	314
Do	15–21	Green, reddened	2.37	.22	2.59	.787	.534	.367	.167	4.80	5.78	10.58	260
May 26		Slightly red	2.92	.40	3.32	.629	.346	.199	.147	5.50	3.87	9.37	119
Do		Red ripe	3.26	.65	3.91	.580	.346	.167	.179	6.18	3.38	9.56	60
June 3		Ripe	3.35	.50	3.85	.433	.288	.134	.154	4.86	3.16	8.02	20
1926													
May 21	8–11	Small	1.84	.39	2.23	.590	1.667	.931	.736	5.23	9.83	15.06	318
Do	12–10	Large	1.94	.16	2.10	.776	1.105	.661	.444	4.73	9.26	13.99	303
May 27	11–20	Small	1.85	.38	2.23	.827	.728	.571	.157	5.12	8.21	13.33	257
Do	15–24	Large								5.40	6.65	12.05	176
June 3	18–27	Greenish red	3.33	.58	3.91	.905	.337	.201	.136	6.28	4.31	10.59	36
Do	18–24	Medium	3.71	.67	4.38	.821	.348	.214	.134	6.46	4.01	10.47	28
Do	21–23	Ripe	4.21	1.12	5.33	.675	.300	.178	.122	7.00	3.46	10.46	15
June 9	21–23	Full ripe	3.72	.22	3.94	.378	.320	.190	.130	5.50	3.22	8.72	10
1927													
May 20	9–18	Green	1.59	.35	1.94	.800	.882	.612	.270	4.60	8.46	13.06	282
May 28	15–21	do	2.04	.54	2.58	.983	.496	.266	.230	5.44	5.98	11.42	187
Do	18–24	White	2.35	.76	3.11	1.010	.500	.330	.170	5.44	5.88	11.32	110
Do	18–24	60 percent red	2.86	.76	3.62	.852	.340	.210	.130	5.84	3.86	9.70	51
June 3	18–24	80 percent red	3.00	.52	3.52	.948	.330	.220	.110	5.56	4.17	9.73	51
Do	18–24	Firm ripe	2.70	1.23	3.93	.790	.266	.144	.122	5.72	2.43	8.15	28
Do	18–24	Soft	3.78	1.15	4.93	.695	.250	.104	.146	6.48	3.40	9.88	22
1928													
May 17	5–11		1.36	1.32	2.68	.780	1.852			6.24	16.08	22.32	334
Do	11–17		2.18	.00	2.18	.780	1.104			5.44	10.04	15.48	296
May 29	12–15	No white	1.75	.55	2.30	.909	.662			4.76	6.58	11.34	174
Do	18–27	Some white	2.18	.68	2.86	.877	.507			5.04	5.20	10.24	123
Do	18–27	Some red	2.32	.92	3.24	.747	.322			4.86	3.69	8.55	105
Do	24–30	Half red	3.01	.69	3.70	.785	.294			5.60	3.71	9.31	45
June 11	24–30	Ripe	3.60	1.23	4.83	.618	.247			6.26	3.24	9.50	53
June 20	24–30	Dead ripe	3.37	.73	4.10	.520	.217			5.66	2.69	8.35	16

TABLE 1.—*Chemical composition and resistance to puncture of strawberry varieties during development and ripening*—Continued

PROGRESSIVE

Date	Diameter	Description	Sugar			Titratable acidity	Astringency			Solids			Puncture test	pH
			Reducing	Cane	Total		Total	Tannin	Nontannin	Soluble	Insoluble	Total		
1925	*Mm*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Grams*	
May 5	5-9		1.60	0.68	2.28	0.929	2.790	2.024	0.766	5.58	10.11	15.69	333	
Do	8-11		1.64	.77	2.41	1.179	2.109	1.639	.470	5.50	8.92	14.42	332	
May 13	9-15		1.95	.16	2.11	.821	.684	.308	.376	4.45	11.21	15.66	261	
Do	12-18		2.35	.27	2.62	.926	.420	.196	.224	5.20	5.65	10.85	214	
Do	12-21	Slightly blushed	2.89	.74	3.63	.940	.302	.103	.199	6.18	4.46	10.64	63	
May 19	15-21		2.68	.43	3.11	.812	.342	.114	.228	5.74	4.47	10.21	153	
Do	18-27	Blushed	2.79	.77	3.56	.800	.250	.104	.146	5.88	3.59	9.47	60	
Do	18-30	Ripe											21	
May 26		Green	2.67	.31	2.98	.509	.366	.140	.226	4.82	3.38	8.20	22	
Do		Ripe	3.58	.63	4.21	.522	.384	.247	.137	5.76	2.84	8.60	8	
May 27		Very ripe	3.96	.75	4.71	.530	.237	.072	.165	6.74	3.44	10.18	5	
1926														
May 21	6-11	Small	1.70	.14	1.84	.783	1.420	1.133	.287	5.31	8.57	13.88	251	
Do	11-17	Medium	2.17	1.31	3.48	.830	.864	.669	.195	5.00	7.00	12.00	211	
Do	17-23	Large	3.43	.00	3.43	.882	.600	.307	.293	5.14	5.69	10.83	165	
May 27	12-24	Green	2.71	.13	2.84	.810	.540	.380	.160	5.19	4.87	10.06	99	
Do	14-27	Medium	3.46	.41	3.87	.805	.410	.316	.094	6.07	3.67	9.74	33	
Do	12-30	Ripe	4.22	.13	4.35	.706	.328	.247	.081	6.80	3.19	9.99	11	
June 3	21-27	Greenish red	2.54	.80	3.34	.787	.383	.186	.197	5.30	3.96	9.26	24	
Do	18-29	Medium	3.21	.49	3.70	.546	.243	.175	.068	5.16	3.25	8.41	14	
Do	18-32	Ripe	3.79	.59	4.38	.452	.312	.172	.140	5.92	2.98	8.90	7	
June 8	18-32	do	2.97	1.02	3.99	.464	.266	.130	.136	5.06	2.71	7.77	10	
1927														
May 20	11-15	Small	1.67	.16	1.83	.936	.839	.504	.335	4.57	7.60	12.17	286	3.48
Do	14-18	Large	1.90	.45	2.35	.994	.562	.322	.240	4.56	6.55	11.11	229	3.38
May 28	12-24	White	2.64	1.08	3.72	1.160	.350	.232	.118	5.80	4.40	10.20	109	3.23
Do	15-21	60 percent red	2.81	1.04	3.85	1.050	.274	.164	.110	5.84	3.83	9.67	58	3.12
Do	15-21	Deep red	3.30	1.14	4.44	.911	.238	.150	.088	6.20	3.20	9.40	14	3.19
June 3	15-24	Red	2.60	1.11	3.71	1.218	.340	.190	.150	6.20	3.81	10.01	40	
Do	18-27	Ripe	3.97	1.92	5.89	.852	.324	.206	.118	7.32	3.16	10.48	16	3.27
1928														
May 17	6-15		1.62	.90	2.52	.884	1.650			5.44	9.18	14.62	311	4.24
June 11		Ripe	4.16	2.25	6.41	.669	.213			7.88	5.95	13.83	16	3.37

SAMPLE

1925													
May 5	6–9		1.20	1.11	2.31	1.089	4.720	2.354	2.366	6.29	10.23	16.52	361	
Do	9–14		1.56	.95	2.51	1.141	3.417	2.521	.896	5.83	8.85	14.68	346	
May 13	5–9		1.47	.19	1.66	.790	1.649	.790	.859	5.09	7.76	12.85	358	
Do	9–15		2.22	.15	2.37	.714	.853	.253	.600	4.74	6.77	11.51	289	
May 19	6–15		3.76	.18	3.94	1.560	2.083	.974	1.109	4.96	6.74	11.70	263	
Do	12–18		2.04	.16	2.20	.810	.654	.428	.226	4.72	5.53	10.25	222	
Do	18–30	Ripening	2.59	.28	2.87	.652	.445	.240	.205	5.41	4.40	9.81	154	
May 26		Green, reddening	2.33	.27	2.60	.646	.429	.243	.186	4.84	3.82	8.66	144	
Do		Medium red	2.53	.49	3.02	.660	.505	.310	.195	4.84	3.20	8.04	100	
Do		Ripe	2.71	.38	3.09	.593	.396	.208	.188	4.96	2.88	7.84	48	
June 5		Very soft	4.45	.06	4.51	.465	.345	.124	.221	6.07	3.24	9.31	10	
1926														
May 21	6–11	Small	1.75	.45	2.20	.642	2.213	1.321	.892	6.06	9.06	15.12	347	
Do	17–21	Large	2.21	.55	2.76	.692	1.373	.820	.553	5.34	7.54	12.88	294	
May 27	12–18	Small	2.14	.66	2.80	.800	1.124	.845	.279	5.66	7.20	12.86	223	
Do	15–27	Large	3.31	.12	3.43	.862	.743	.480	.263	5.82	5.40	11.22	132	
June 3	18–30	Half ripe	3.50	.14	3.64	.668	.451	.316	.135	5.66	3.43	9.09	25	
Do		Ripe	4.53	.49	5.02	.675	.405	.231	.174	6.70	3.11	9.81	14	
June 11		Full ripe	4.27	.50	4.77	.477	.290	.189	.101	6.10	2.72	8.82	14	
1927														
May 28	12–18	Green	1.28	.40	1.68	1.115	1.090	.728	.362	5.12	8.05	13.17	235	
Do	18–24	Some white	1.65	.46	2.11	.983	.676	.416	.260	4.64	5.10	9.74	151	
June 3	12–27	5 percent red	2.84	.39	3.23	1.120	.570	.346	.224	5.92	4.51	10.43	90	
Do	12–27	90 percent red	3.41	.68	4.09	1.080	.458	.308	.150	6.64	3.19	9.83	52	
Do		Firm ripe	3.97	1.41	5.38	.857	.376	.222	.154	7.52	3.60	11.12	36	

GENERAL COURSE OF PHYSIOLOGICAL CHANGES DURING DEVELOPMENT

FIRST SAMPLING

For reasons already stated, the size and age of the berries making up the initial samples varied considerably from variety to variety and from year to year. Considered collectively, the initial samples of 1925 and 1928 were very nearly identical in size and presumably in age; those of 1926 and 1927 were distinctly larger.

In common with a number of fruits of varied types (*3*), the young strawberry shows very definite and consistent chemical and physical characteristics. When compared with the later stages, the initial samples of all varieties in all years are characterized as a group by the possession of maximum resistance to puncture, maximum total solids, maximum insoluble solids, and maximum total astringency. For reasons discussed later, the absolute values for all these constituents vary considerably from variety to variety and from year to year, but without exception the smallest sample of any variety taken in any given year had a maximum content of each of these constituents which progressively declined through the series of samples subsequently taken. Further, the maximum values for total and insoluble solids found anywhere in the series were present in the initial samples of New York, Portia, and Chesapeake, in 1928, which were taken when most of the berries had some of the petals still adhering and which were judged to be the youngest as well as the smallest berries obtained in the course of the work.

The total solids of the young fruits are characterized by the preponderance therein of insoluble solids, which make up 60 to 70 percent of the total, the percentage being maximum in the youngest berries obtained (Portia and New York, 1928).

The soluble solids are quite variable in composition. The outstanding and constant characteristic is the very large amount of astringent material as indicated by the usual method of titration with potassium permanganate and calculation in terms of the reducing power of chestnut tannin. In all the very young samples, permanganate-reducing substances when calculated as tannins make up 30 percent or more of the soluble solids, or more than 10 percent of the total solids (Aroma, 1925; Chesapeake, 1925, 1928; Dunlap and Gandy, 1925; Missionary, 1925, 1926). The nature of this material is problematical and its statement in terms of the conventional tannin factor serves for convenience in comparison only. That it is actually much smaller in amount than these figures indicate is shown by the fact that for the youngest stages the sum of total sugars, titratable acids, and astringents calculated as tannin exceeds the total sum of soluble solids as determined by drying the alcoholic extract. All that can be said at present is that the young fruit is characterized by the presence of considerable quantities of readily oxidizable substances which are most abundant in the very young fruit and which decrease with age.

The nontannin fraction of the astringent material (portion not precipitable by gelatin) varies rather widely both in absolute amount and in the proportion it forms of the total astringents, but in every instance it is largest in the first sample of a series. Both total and nontannin astringency show very large and abrupt decreases with increase in age

and size of berries. This behavior they share with a variety of fruits of widely different types (*3*), but no other fruit thus far examined appears to compare with the strawberry in the amount of astringent material present in the very young fruit.

The sugar content of the young fruit varies in amount and in the proportion of reducing sugars and sucrose entering into its make-up. In general, sugars constitute 30 to 40 percent of the soluble solids, but in a few cases the percentage is materially higher. Free reducing sugars in most cases make up 60 to 90 percent of the total sugar, but in a few instances sucrose nearly equals or even exceeds reducing sugars. The occurrence of high sucrose content is quite erratic, a variety in which it is relatively high in one year having very little at a corresponding stage in other years.

Titratable acidity is in general quite high in the initial samples, its absolute amount fluctuating rather widely from year to year in a given variety. Active-acidity determinations were made only in 1927 and 1928; the results indicate that active acidity is at a minimum in the youngest fruits obtained and undergoes a pronounced rise during subsequent development. Titratable acidity may undergo a similar but less pronounced increase or may remain more or less stationary throughout the growth of the berry, decreasing slightly in the fully ripe fruit.

The resistance of the fruit to puncture is greatest in the youngest fruits and decreases progressively as development proceeds. In 2 or 3 instances the larger berries taken at the first sampling were slightly firmer than the smaller ones, but in general the smallest fruits obtainable were the firmest.

In summarizing, it may be said that very young fruit, at the time the petals are withering and falling or soon thereafter, is characterized by maximum firmness as measured by resistance to puncture, maximum total solids, maximum insoluble solids, total astringency and nontannin astringency, high acidity, and a rather variable but relatively low total-sugar content consisting predominantly of free reducing sugars with widely varying amounts of sucrose.

SECOND SAMPLING

The fruit collected at the second sampling had entered upon the phase of rapid enlargement on the percentage basis as indicated primarily by increase in volume. The system of grading by size herein employed included in any given sample berries differing by 3 or 4 mm in transverse diameter, the lower limit being the upper limit of the preceding sample. No estimates of average volume of berry were made, but the second-stage fruits averaged 2 to 3 times the volume of the first-stage fruits.

In some instances the larger berries obtained at the initial sampling showed well-defined physical and chemical differences from the smaller fruits taken at the same time; in others, such differences were less distinct. Without exception the fruit obtained at the second sampling, which was made 6 to 10 days after the first, showed distinct and consistent changes in practically every constituent determined.

The most pronounced change was a marked decrease in total solids, which was accompanied in all cases by a decrease in insoluble solids and in nearly all by some reduction in soluble solids. Total and nontannin astringents showed a very marked decrease, proportionally greater than in any other constituent. Total sugars were somewhat variable; in the majority of cases they were slightly lower than at the initial sampling; in the others they were practically stationary or showed a slight increase. In general, those varieties which were exceptionally high in sugar at the first sampling showed rather pronounced decreases; those which were low at that time showed no decrease or an actual gain, with the result that the ratio borne by total sugars to soluble solids was less variable at the second sampling than at the first. Sucrose in the great majority of cases had decreased; in others it remained constant or increased slightly. In no case was there any significant increase or any tendency toward permanent increase of sucrose. Titratable acidity in nearly all cases increased; in the exceptions it was highest in the first sample and declined somewhat at the second sampling. In every case in which hydrion concentration determinations were made, the active acidity had very appreciably increased over that of the first sample. In all cases there was a considerable decrease in the resistance of the fruit to puncture.

CHANGES UP TO WHITENING STAGE

To describe in detail the changes that occur from one sampling period to the next for the various stages up to the point at which the fruits begin to lose their chlorophyll and become blushed would involve much repetition. The whole period is one of progressive decrease, initially rather rapid in total solids, insoluble solids, and astringent material. There is a less pronounced decrease, not present in every case, in the soluble solids. Total sugars and titratable acidity are rather variable in behavior, usually increasing slightly but frequently fluctuating irregularly without much net change. The explanation of these facts is clear (*3*). The period is one of rapid increase in size, due primarily to distention of the cells by absorption of water. The rate of water intake greatly exceeds the rate of formation of structural material. In consequence the percentage of insoluble solids and of total solids present in the fruit progressively decreases as the process of distention with water continues. Meantime, sugars are being transported into the fruit from the leaves at a rate which continually fluctuates with changes in the rate and amount of photosynthetic activity. Some of the incoming sugar is used up in respiration; some is employed in the formation of cell walls and structural material; the remainder accumulates as sugar. Acids are being produced in the fruit as a result of katabolic activities at a rate which fluctuates with changes in the environmental conditions. Whether sugar content shall show an increase in amount from day to day will be determined by the relation between rate of formation and transport of sugar, rate of respiration, and rate of absorption of water. In a period of deficient moisture supply and favorable conditions for photosynthetic activity, the growing fruit would show a rise in sugar content; under the opposite conditions a decrease would occur. In consequence, the composition of the fruit as regards sugar and acid content at any point in the period of rapid

growth is determined by the rate at which absorption of water is occurring in its relation to the rates of photosynthetic and respiratory activity. Because of the progressive accumulation of water the growing fruit decreases progressively in total and insoluble solids throughout the period of rapid growth. Meanwhile the content of sugar and acid fluctuates irregularly by reason of variations in rate of production, which at one time lags behind, at another forges ahead of the accumulation of water. In spite of irregularities due in part to sampling error, there is a clear tendency to an increase in both sugar and acid content with increase in size. Resistance to puncture decreases steadily throughout the period of rapid growth.

CHANGES DURING WHITENING STAGE

The stage of whitening, in which the fruit has practically attained full size and is losing its chlorophyll and beginning to develop a blush, is definitely characterized by a number of chemical changes. The progressive increase in water content which accompanies the period of rapid growth practically ceases and water content becomes nearly or quite stationary at a value that is maximum for the whole life history. Conversely, total solids become stationary at a minimum value before beginning to increase somewhat as the fruit ripens. Titratable acidity, which as a rule has been increasing up to this point, reaches a maximum from which it subsequently declines rather rapidly. Active acidity attains a maximum from which it subsequently decreases somewhat as ripening proceeds. Soluble solids, which have declined somewhat or remained relatively stationary up to this point, show the beginning of an increase which continues up to ripeness. Total sugars, which have previously made slow and irregular gains, increase markedly, and this increase is practically wholly in the form of reducing sugar, the amount of sucrose present remaining stationary or declining somewhat. The total sugars, which during the period of rapid growth make up 50 percent or less of the soluble solids, now compose 60 to 65 percent of the total soluble matter but only 30 to 40 percent of the total solids of the berry. Total astringency, which has been decreasing rather rapidly up to whitening, enters upon a stage of slow and irregular decline, continued decrease in "true tannins" being more or less completely balanced by increase in the nontannin fraction. Insoluble solids, which have declined quite rapidly up to this point but which have hitherto exceeded soluble solids in amount, drop below soluble solids and continue to decrease at a slower rate to full ripeness. Resistance to puncture ranges between 140 and 100 g, or between one-third and one-fourth of that found at the time the petals are falling.

CHANGES DURING RIPENING

The transition from the whitening stage to full ripeness is accompanied by an increase in total solids, ranging in amount from very slight to very considerable, which only very exceptionally fails to occur. This increase is due to a rapid increase in total sugars, which considerably more than compensates for a simultaneous decrease in insoluble solids. While sugars at the whitening stage made up only 60 to 65 percent of the soluble solids and not more than 40 percent of the total solids of the fruit, in the ripe fruit sugars constitute 70 to

80 percent of the soluble solids and 50 percent or more of the total solids. The percentage of sucrose in the total sugars is highly variable in the ripe fruit, as is the case throughout development, and its occurrence is sporadic, the extremes in the same variety ranging between 3 percent and 30 percent of the total sugar present in different years. In general, 80 to 90 percent of the sugar of the ripe fruit consists of reducing sugars. Titratable acidity declines rather rapidly from whitening to full ripeness, then becomes stationary or may rise slightly in the overripe fruit. Active acidity also declines in varying amount. Total astringency declines slowly, increase in the nontannin fraction partially counterbalancing the continued decrease in tannin. Resistance to puncture decreases rapidly, the general average of 100 to 140 g found in the various varieties at whitening stages becoming reduced to 15 to 30 g at firm ripeness and sinking to 5 to 10 g in overripe fruit.

Summarizing the general course of development in the fruit, the earliest stages obtainable are characterized by a high total-solids content consisting chiefly of insoluble materials, a very high content of substances which readily reduce potassium permanganate, variable but relatively low sugar content, moderately high titratable acidity, and low active acidity. The period of rapid increase in volume is one of progressive increase in water content with a resultant decided decline in content of total solids, insoluble solids, and total astringency. In the earlier stages there is a varying and less pronounced decline in soluble solids with which there is generally associated a decrease in the total sugars; later, soluble solids become practically stationary and sugars may show an increase. Titratable acidity increases, active acidity shows a very pronounced increase. At the whitening stage, as the berry passes over from the phase of rapid growth into the ripening processes, water content, titratable acidity, and active acidity attain maximum values. The ripening of the fruit is attended by a marked increase in total sugars and soluble solids; an increase in total solids; and a decrease in total astringency, titratable acidity, active acidity, and insoluble solids. The firmness of the fruit as measured by resistance to puncture decreases throughout the whole period of development and ripening, most rapidly as the fruit passes from whitening to ripeness.

RELATION OF CHANGES IN CHEMICAL CONSTITUENTS TO ONE ANOTHER AND TO RESISTANCE TO PUNCTURE

In the preceding section the changes in chemical composition and in the resistance to puncture occurring in the strawberry during development and ripening have been pointed out and discussed. It now seems advisable to examine in more detail the nature of the relationships which exist among these several changes, and also to ascertain whether these relationships throw any light upon the behavior of the fruit in the course of the various canning and preserving processes.

It is obvious from the preceding discussion that the physical character and chemical composition of the strawberry are functions of its stage of maturity. The growth and development of the berry are influenced by many factors, some of which may affect one phase of its development to one degree and another phase to a different degree, or even in a different manner. Among these factors may be men-

tioned character and composition of soil, fertilizer applications, weather conditions, available soil moisture, prevalence of leaf diseases, closeness of planting, number of berries borne upon the plant, and position of the flower cluster on the plant and of the berry in the flower cluster. It is difficult or impossible to evaluate the effects of these factors upon a given lot of material. For this reason a single series of samples of field-grown fruit may yield results that leave the general relationships between physical and chemical characters in considerable doubt. Since there were available in this study 40 series of samples made up of 278 separate lots of fruit, the material seemed to offer an opportunity to determine more accurately the relationships existing among the several constituents of the berry than would be possible with a smaller number of samples.

Study of the data with reference to maturity of this material has been considerably handicapped by the fact that the exact age of the berries making up any given sample was not known. It was not possible to tag the opening flowers, which would have made it possible to collect samples of any desired age. The approximate age of the fruit was known, however, and it was apparent that its resistance to puncture would give a fairly accurate measure of its degree of maturity. From a practical standpoint the firmness of the fruit is one of its most important characteristics. It therefore seemed desirable to study the relationship between degree of resistance to puncture and the amounts of the various chemical constituents of the fruit. Such a study seemed to be justifiable, for if there is a definite relationship between the resistance of the fruit to puncture and the amounts of the various chemical constituents present, the making of puncture tests would afford an inexpensive, readily obtainable index of the composition of the fruit.

That there is a correlation between the resistance to puncture offered by the fruit and its chemical composition is immediately apparent from an examination of the analytical data. It will be noted that the correlation is not perfect, but just how nearly so it may be is not obvious from inspection. Moreover it is not clear whether the correlation is as high at one stage of development or maturity as at another. In other words, the question arises whether the function is linear or curvilinear. Further, if the data are not in complete agreement, a question arises as to the extent of the variations and as to the reliability of the average values determining the location of the lines or curves representing the relationships.

It is also obvious from an inspection of the data that some degree of correlation exists between the ratio of the insoluble solids to the soluble solids and the chemical composition of the fruit. Precisely the same questions arise in regard to this relationship as to that between firmness and composition, with a like impossibility of obtaining definite answers by inspection of the data. In order to answer these questions as fully as possible, statistical methods were applied to the data, and the results are presented as a series of graphs. These present in part the relationships between resistance to puncture and certain chemical constituents, in part the relationships between the ratio of insoluble to soluble solids and these same constituents.

As the material at hand consisted of samples of 12 varieties of strawberry, an attempt was made at the outset to classify the data

with respect to variety. Thus there were formed 12 groups of samples of widely varying size, which markedly increased the magnitude of the standard error of estimate and resulted in the production of broken and highly irregular curves. The combination of all the data from the 278 samples into one class resulted in the production of very much smoother curves, and such a combination has accordingly been made. It should therefore be remembered that a part of the variation shown in the graphs is to be attributed to varietal differences.

The method employed in making the calculations is one described in detail by Ezekiel (*11, pp. 91–97, 111–124*), and may be stated briefly as follows. The values of the given chemical constituent under consideration are regarded as the dependent variable y, and are plotted against the ratio of insoluble to soluble solids as the independent variable x. The pairs of values for each of the 278 samples were tabulated and then plotted on coordinate paper on a large scale, each pair of values being represented by a small circle. The line representing the average for all these points was then determined freehand, as follows: The values were divided into groups along the x axis, and the values of these group averages were each represented by a point; these points were connected by a line which was generally somewhat irregular. In order to eliminate these irregularities larger group averages were made or the groups were combined so as to establish intermediate points. Finally, a smooth curve was drawn in such a position that the deviations of the points on either side of the line appeared to be equal. This line represents the regression of the dependent variable upon the independent variable, and gives a complete picture of most of the facts in regard to the relationship between the two variables. The vertical distance of each point from the line of regression was read directly from the graph. The value of each of these deviations was recorded with its proper sign, and added algebraically to the actual value of the dependent variable to which it corresponded. A set of estimated values was thus obtained. The standard deviation of these estimated values, divided by the standard deviation of the actual values, gives the coefficient of correlation. Since certain corrections have to be made it is necessary to employ formulas which take these into account. The symbols and formulas and the general method employed are as stated by Ezekiel (*11, pp. 399–403*). The formulas are numbered as in Ezekiel's list.

x=independent variable.
y=dependent variable (actual value).
y'=estimated values of the dependent variable.
z=residual or difference between actual and estimated values of the dependent variable.
M=mean.
σ=standard deviation.
S=standard error of estimate.
r=coefficient of correlation.
ρ=index of correlation.

$$\sigma_x = \sqrt{\frac{\Sigma(X^2)}{n} - n(M_x)^2} \tag{5}$$

$$r_{yx} = \frac{\sigma_y'}{\sigma_y} \tag{21}$$

$$\bar{r}^2_{yx} = 1 - (1 - r^2)\left(\frac{n-1}{n-2}\right) \tag{25}$$

$$\rho_{yx} = \frac{\sigma_{y''}}{\sigma_y} \tag{22}$$

$$\bar{\rho}^2_y = 1_z - (1 - \rho^2)\left(\frac{n-1}{n-m}\right) \tag{26}$$

$$\bar{\rho}^2_{yx} = 1 - \left(\frac{\sigma^2_{z''}}{\sigma_y{}^2}\right)\left(\frac{n-1}{n-m}\right) \tag{29}$$

$$\bar{S}^2_{yx} = \frac{n\sigma^2_z}{n-2} \tag{23}$$

$$\bar{S}^2_{y \cdot f(x)} = \frac{n\sigma^2_{z''}}{n-m} \tag{24}$$

$$\sigma r_{yx} = \frac{1 - r^2}{\sqrt{n-2}} \tag{71}$$

$$\sigma \rho_{yx} = \frac{1 - \rho^2}{\sqrt{n-m}} \tag{72}$$

The results of the calculations are summarized in table 2; the various curves to which they relate are shown in figures 1 to 12.

TABLE 2.—*Coefficients and indices of correlation and standard errors for the correlations between resistance to puncture, ratio of insoluble to soluble solids, and various chemical constituents of the strawberry during development and ripening*

Independent variable	Dependent variable	Coefficient or index of correlation	Standard error of the coefficient or index of correlation	Coefficient of determination	Standard error of estimate
Resistance to puncture	Ratio of insoluble to soluble solids.	+0.917	±0.009	0.841	0.207
Do	Percentage of insoluble solids	+.882	±.014	.778	1.125
Do	Percentage of soluble solids	[1].641	±.033	.412	.805
Do	Percentage of total solids	+.754	±.026	.568	1.455
Ratio of insoluble to soluble solids.	do	[1].884	±.013	.781	1.357
Resistance to puncture	Percentage of total sugars	−.817	±.019	.668	.741
Ratio of insoluble to soluble solids.	do	−.871	±.014	.759	.584
Resistance to puncture	Percentage of titratable acidity	[1].494	±.045	.245	.223
Ratio of insoluble to soluble solids.	do	+.547	±.041	.299	.204
Resistance to puncture	Percentage of total astringency	+.926	±.008	.857	.459
Ratio of insoluble to soluble solids.	do	+.710	±.029	.504	.685
Percentage total sugar	Percentage of titratable acidity	−.290	±.54	.084	.247

[1] Index. The curve is in part positive, in part negative.

RATIO OF INSOLUBLE TO SOLUBLE SOLIDS IN RELATION TO RESISTANCE TO PUNCTURE AND THEIR SIGNIFICANCE AS MEASURES OF MATURITY

Since the exact age of the fruit comprising a sample was not known, it was impossible to determine exactly how well the degree of resistance to puncture measured the degree of maturity, for neither set of values could be checked against the age of the sample. As a means of checking the results of the puncture test, which is a physical method of estimating maturity, it was desirable to employ another and entirely different method, chemical in character, for estimating stage of matur-

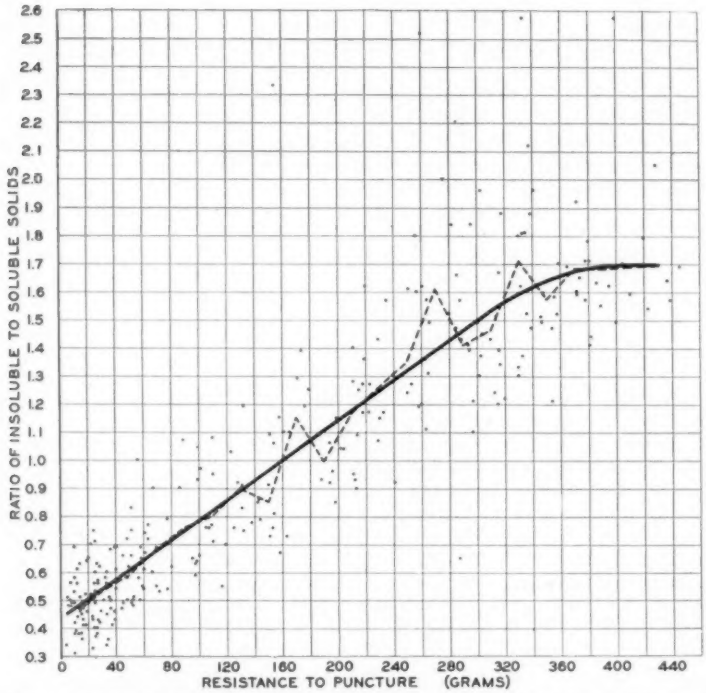

FIGURE 1.—Relationship between ratio of insoluble to soluble solids and resistance to puncture during development of the strawberry. Plotted from table 1. Includes all values for all varieties for four seasons. Broken lines indicate position of the group averages; the heavy line is a smoothed curve. The coefficient of correlation is 0.917 and the standard error of estimate 0.207.

ity. An examination of the analytical data in some detail appeared to indicate that the ratio of insoluble solids to the soluble solids of the fruit is also a good measure of the stage of maturity; it was therefore chosen to serve as a check upon the results obtained by the use of the puncture test.

In order to ascertain the degree of relationship between these two measures of maturity, values for the ratio of insoluble to soluble solids were plotted against values for the puncture test, the line of regression being determined as drawn freehand in the manner already described. The result is shown in figure 1. It may be pointed out that for low values of both ratio and puncture test the fruit was fully

ripe; for high values of both measures the fruit was very immature. The line of regression is very nearly a straight line, but the data seem to justify a slight curve downward of the end of the line as extremely high values of the puncture test are reached. This shows that, on an average, changes in the values for the ratio of insoluble to soluble solids are directly proportional to changes in the resistance of the fruit to puncture, except for a small group of very high values. It may be noted that the points representing the individual pairs of values do not fall exactly upon a line but form a rather narrow band, the center of which is a line representing the average of all values.

From the amount and character of the scatter about the line of regression it is evident that in individual cases the change in one of the measures employed is not accompanied by a corresponding change in the other. This of course means that if estimates of the degree of maturity were made for each of the samples in hand by the two methods of estimation separately the results in the individual cases would differ somewhat. While some part of the scatter, especially the widely aberrant values occurring here and there in the graph, are undoubtedly due to errors in making the analytical determinations, it is believed that environmental conditions may have been such as to affect one of these criteria of maturity without affecting the other to the same degree.

The coefficient of correlation was determined and found to be 0.917, which indicates a very good agreement between the two measures of maturity. The coefficient of determination is 0.84. The standard error of estimate (0.207) shows that in 1 out of 3 cases the actual values of the ratio of insoluble to soluble solids will fall below or exceed the estimated values by as much as 0.207 percent. The reliability of the line of regression is not the same throughout its length, but decreases when the values are very high; in other words, with very young samples of fruit.

INSOLUBLE SOLIDS IN RELATION TO RESISTANCE TO PUNCTURE

In figure 2 the values for content of insoluble solids are plotted against the values for the puncture test. The points, with relatively few exceptions, fall closely about a locus which appears to be a straight line. For low values of the puncture test the content of insoluble solids is low; for high values it is high. The correlation is consequently positive and a coefficient of 0.882 shows a rather high degree of correlation. From the coefficient of determination it is seen that 78 percent of the total variation in the resistance to puncture of the berries is accounted for by differences in insoluble solids, leaving only 22 percent to be explained by all other causes, including variable differences. The standard error of estimate (1.125) indicates that on an average two-thirds of the values for insoluble solids will fall within the limits of 1.125 percent above or below the line of regression. The reliability of the line, however, is not so great where the values are high as where they are low, as it evidenced by the increase of scatter in the high values (fig. 2). Since high values of the puncture test are indicative of immaturity, it is evident that the percentage of insoluble solids in the fruit is inversely proportional to the degree of maturity of the berry.

SOLUBLE SOLIDS IN RELATION TO RESISTANCE TO PUNCTURE

In figure 3 the percentages of soluble solids in the various samples are plotted against the corresponding values of the puncture test.

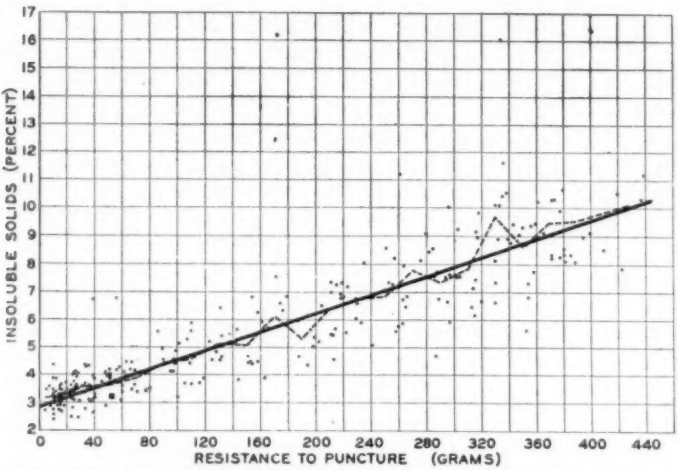

FIGURE 2.—Relationship between percentage of insoluble solids and resistance to puncture during the development of the strawberry, plotted from the data of table 1 and including all values for all the varieties for the 4 years. Broken lines indicate the position of the group averages; the heavy line is a smoothed curve. The coefficient of correlation is 0.882 and the standard error of estimate 1.125.

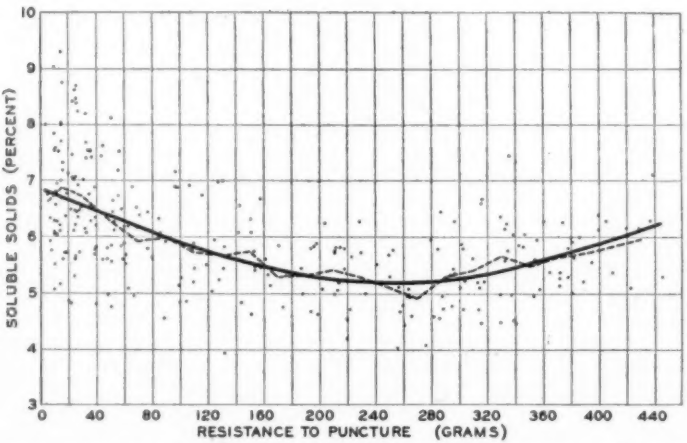

FIGURE 3.—Relationship between percentage of soluble solids and resistance to puncture during the development of the strawberry, plotted from data of table 1. The index of correlation is 0.641 and the standard error of estimate 0.805.

The points representing the various samples fall in a broad band about a locus which appears to be a pronounced curve, the scatter about the mean increasing very materially as low values for the

resistance to puncture are reached. The form of the curve is the resultant of several chemical changes differing in direction but occurring concurrently during the development of the fruit. The three groups of substances mainly concerned are sugars, acids, and tannins. Tannins and acids are high in the immature fruit and decrease with advancing maturity; sugars are low in the young fruit and rise rapidly as maturity is reached. The resultant line of regression is a curve which indicates a negative correlation where the values of the puncture test are low and a positive correlation where the puncture-test values are high. In other words, the correlation of soluble solids with puncture test is positive during the period just subsequent to flowering but becomes negative during the ripening period. The index of correlation of 0.641 is very considerably less than that found for insoluble solids. The coefficient of determination shows that 41 percent of the

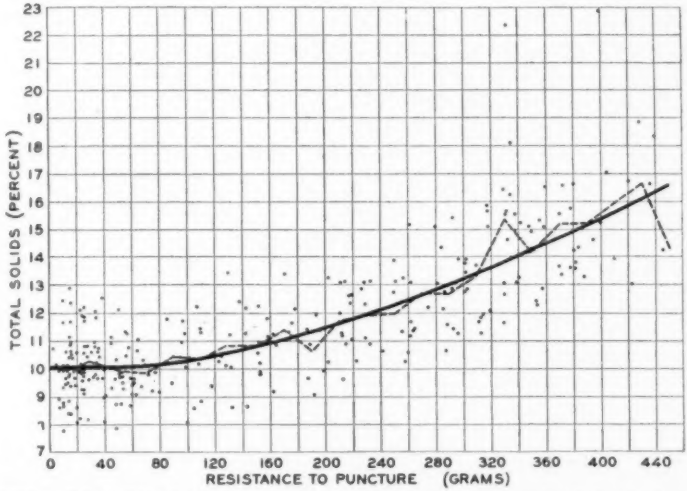

FIGURE 4.—Relationship between percentage of total solids and resistance to puncture during development and ripening of the strawberry, plotted from the data of table 1. The coefficient of correlation is 0.754 and the standard error of estimate 1.455.

total variation in resistance to puncture may be accounted for by the differences in soluble solids, leaving 59 percent to be attributed to all other causes. This is a considerably larger percentage of unexplained variation than was the case with the insoluble solids. It is due not so much to the greater variation in the soluble solids as to a lack of a proportional change in soluble solids with change in resistance to puncture. The standard error of estimate (0.805) is numerically lower for soluble solids than for insoluble solids.

TOTAL SOLIDS IN RELATION TO RESISTANCE TO PUNCTURE

The results obtained when total solids of the fruit were plotted against resistance to puncture are presented in figure 4. The points are distributed over a broad band and the line of averages forms a rather pronounced curve. For puncture tests ranging from 5 to 80 g there is on an average little change in the percentage of total solids,

although the scatter is somewhat wider in this portion of the graph than elsewhere. This indicates that there is no correlation for the values in this range. For values of the puncture test above 80 g the percentage of total solids progressively rises; that is, resistance to puncture and percentage of total solids increase together. A change of a given magnitude in resistance to puncture is not accompanied by the same amount of change in the percentage of solids for all values of the puncture test. Despite the lack of correlation over part of the range of values, the coefficient of correlation is 0.754. This is a fair degree of correlation and the index of determination shows that 57 percent of the total variation is accounted for, leaving 43 percent as due to all other causes. The standard error of estimate (1.455) shows that two-thirds of the values lie within limits of 1.455 percent above or below the regression line.

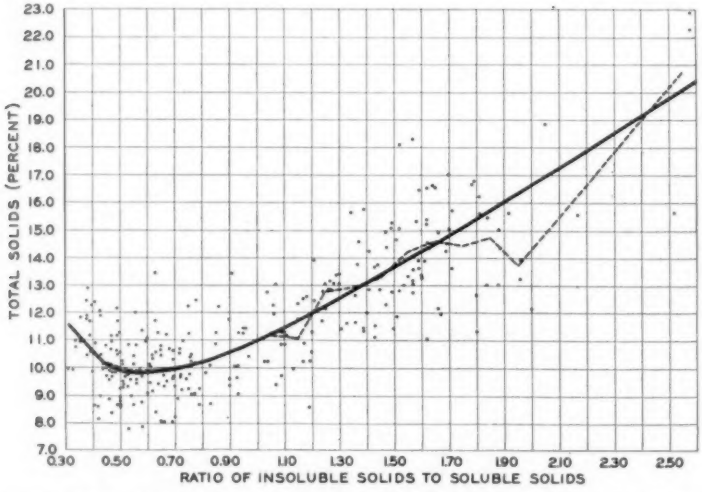

FIGURE 5.—Relationship between percentage of total solids and the ratio of insoluble to soluble solids during the development and ripening of the strawberry, plotted from the data of table 1. The index of correlation is 0.884 and the standard error of estimate 1.357.

The form of the curve is due very largely to changes occurring in the developmental period of the fruit. The curve is the resultant of the joint effect of concurrent changes in a number of substances, some of which are increasing while others are decreasing.

In view of the large standard error of estimate and the large percentage of the variation left unexplained, it seemed worth while to plot total solids against the ratio of insoluble to soluble solids in order to ascertain how closely the results would check with the picture of relations just given, and this was accordingly done.

TOTAL SOLIDS IN RELATION TO RATIO OF INSOLUBLE TO SOLUBLE SOLIDS

Total solids have been plotted against the values for the ratio of insoluble to soluble solids in figure 5. For low values of the ratio of insoluble to soluble solids the total solids are low; and for high values the total solids are also high; that is, for high values of the ratio of

insoluble to soluble solids and for high values of the resistance to puncture, the fruits are very immature, and for low values they are mature. Intermediate values represent intermediate stages of maturity. The points representing the various pairs of values for total solids and the ratio of insoluble to soluble solids are rather symmetrically distributed around a line which is a pronounced curve. In general it is quite similar to the puncture-test curve of figure 4, but in one respect the two curves are quite different. The curve for solids plotted against resistance to puncture was quite flat for values of resistance to puncture ranging from 5 to 80 g, that is, in that portion of the curve representing the ripening period. In the corresponding portion of the curve for solids plotted against the ratio of insoluble to soluble solids, the curve first turns sharply downward, indicating a negative correlation, then changes direction, becoming nearly flat, after which it rises like the curve of figure 4 throughout the remainder of its length. Its direction in this latter portion indicates that there is a strong positive correlation with the ratio of insoluble to soluble solids, as was the case with the like portion of the curve for solids plotted against resistance to puncture. The extreme opposite end of this curve is negative, while the corresponding portion of the curve for solids plotted against resistance to puncture shows no correlation during growth and up to the onset of ripening, indicating that the berry at this period has its highest moisture content, after which solids rise again as the fruit becomes fully ripe. These facts are not shown by the curve for solids in relation to resistance to puncture. A detailed study of the two curves in connection with notes made at the time of picking as to the approximate age, color, and size of the fruit leads the writers to the conviction that the curve for relationship of total solids to the ratio of insoluble to soluble solids gives a truer picture of the changes in total solids during the development and ripening of the fruit than does the curve for relation of total solids to resistance to puncture. This conviction is reinforced by the fact that the index of correlation (0.884) is higher and the standard error of estimate (1.357) lower than for the curve for solids plotted against resistance to puncture; also that a considerably larger proportion of the variation, 78 percent as against 57 percent, is accounted for. All the facts point to the conclusion that while there is in general good agreement for the curves, that of figure 5 is more reliable than that of figure 4, particularly in that portion representing the ripening period of the fruit.

TOTAL SUGARS IN RELATION TO RESISTANCE TO PUNCTURE

In figure 6 the percentages of total sugar have been plotted against resistance of the fruit to pressure. For low values of the puncture test total sugars are high; for high values they are low. The correlation between sugars and resistance to puncture is therefore negative. The values are distributed about a line which is a pronounced curve for part of its length, becoming a horizontal line in its right-hand portion. A line of regression of this character shows that a unit change in the value of the puncture test is not accompanied by the same amount of change in percentage of sugar at all stages throughout the development. Such a change in puncture test when the resistance of the fruit to puncture is low, that is, after the ripening process has set in, is accompanied by a much larger change in the percentage

of sugar than is the case for high values of the puncture test, that is, in immature fruit. An index of correlation of 0.817 shows a fairly good correlation, and the index of determination indicates that 67 percent of the variation is accounted for by differences in the puncture test, leaving 33 percent to be explained by all other factors. As the varieties show somewhat wider varietal differences in sugar content than in other constituents, a portion of this unexplained variation is unquestionably due to varietal differences, but variations in environmental conditions and errors of determination also have an influence. The standard error of estimate is 0.741 indicating that on an average two-thirds of the values lie between the limits 0.741 percent above and 0.741 percent below the line of regression. The deviation of the points from the line becomes somewhat greater during the period of

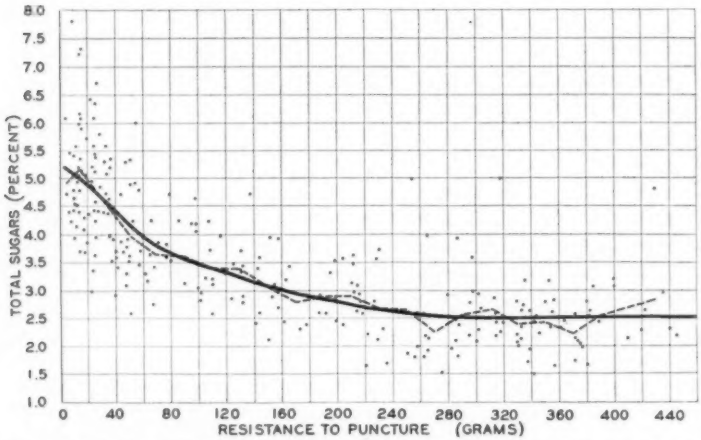

FIGURE 6.—Relationship between percentage of total sugars and resistance to puncture during the development and ripening of the strawberry, plotted from the data of table 1. The index of correlation is 0.817 and the standard error of estimate 0.741.

ripening, that is, as the values for the puncture test become low. This may mean that the puncture test is less reliable as a measure of maturity as the berries approach full ripeness than when they are still quite firm, or it may mean that the berries are more influenced by environmental factors at this stage of maturity than at earlier stages.

TOTAL SUGARS IN RELATION TO RATIO OF INSOLUBLE TO SOLUBLE SOLIDS

In view of the uncertainties just suggested it seemed advisable to plot total sugars against the ratio of insoluble to soluble solids (fig. 7). It will be noted that the curve, while in general similar to the curve showing relation of total sugars to resistance to puncture, is more pronounced. The index of correlation (0.871) is higher and the error of estimate (0.584) is lower, indicating that the curve is somewhat more reliable than that of figure 5, especially in the period of ripening of the fruit. From this it may be inferred that the pressure test becomes a somewhat less trustworthy index of stage of maturity as the fruit enters the period of ripening than it is in the case of immature and growing fruit.

TITRATABLE ACIDITY IN RELATION TO RESISTANCE TO PUNCTURE

Figure 8 presents the results obtained when the percentages of titratable acidity of the various samples are plotted against their

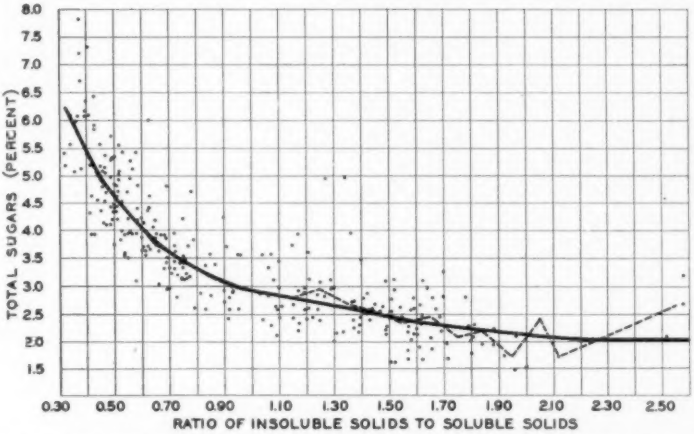

FIGURE 7.—Relationship between percentage of total sugars and ratio of insoluble to soluble solids during the period of development and ripening of the strawberry, plotted from data of table 1. The index of correlation is 0.871 and the standard error of estimate 0.584.

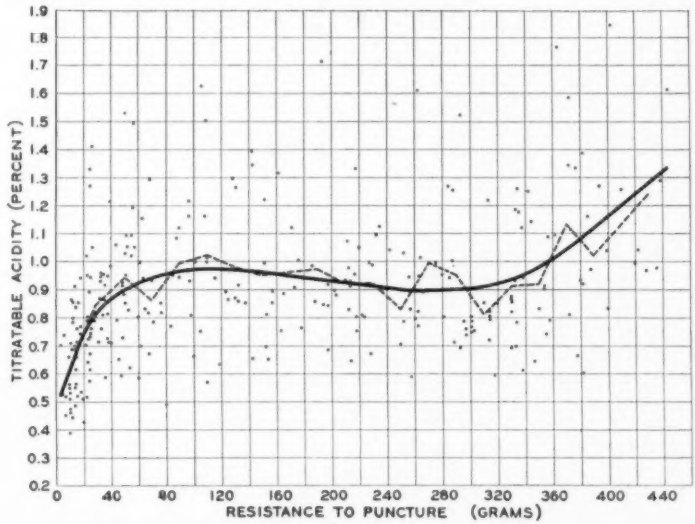

FIGURE 8.—Relationship between percentage of titratable acidity and resistance to puncture during development and ripening of the strawberry, plotted from data of table 1. The index of correlation is 0.494, and the standard error of estimate 0.223.

resistance to puncture. It is obvious that the titratable acidity to a considerable degree varies independently of the resistance to puncture. For low values of the puncture test the acidity is generally

low; for high values it is higher. The curve first rises sharply with increase in resistance to puncture in the region between 5 and 80 g, then becomes nearly horizontal, finally rising again with values of the puncture test ranging from 350 to 450 g. While the final upward turn of the curve follows the group averages very closely, its form must be regarded as somewhat questionable in view of the wide scatter which is apparent. If the final upward portion of the curve be omitted as questionable, it is evident from the form of the curve that there is a good positive correlation between resistance to puncture and titratable acidity throughout the ripening period, with very little or no correlation throughout the period beginning a few days after blooming and extending up to the onset of ripening.

The index of correlation is 0.494, which is quite low. The coefficient of determination indicates that 24.5 percent of the total variation in

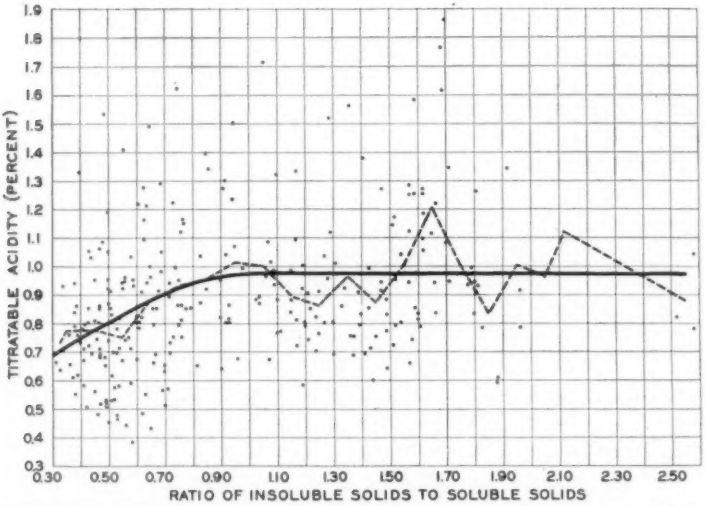

FIGURE 9.—Relationship between percentage of titratable acidity and ratio of insoluble to soluble solids during the development and ripening of the strawberry, plotted from data of table 1. The index of correlation is 0.547 and the standard error of estimate 0.204.

acidity is accounted for by variation in resistance to puncture, leaving 74.5 percent to be attributed to other causes. The standard error of estimate (0.223) indicates that one-third of all the values fall outside the limits of 0.223 percent above or below the line of regression. In terms of the total acidity of the fruit, this is a very considerable variation.

TITRATABLE ACIDITY IN RELATION TO RATIO OF INSOLUBLE TO SOLUBLE SOLIDS

Because of the low correlation between titratable acidity and resistance to puncture, the correlation between titratable acidity and the ratio of insoluble to soluble solids was determined. The results are presented in figure 9.

Throughout most of its extent the curve is similar to that of figure 8 for titratable acidity in relation to resistance to puncture. The chief

difference is in that portion of the curve derived from the very young fruits, which shows no such upward turn as does the curve for acidity in relation to resistance to puncture. The form of the curve indicates no correlation in the case of fruits that are immature, with a fairly good correlation in the case of fruits that have entered upon the ripening period. The index of correlation is 0.547, as compared with 0.494 for the acidity-puncture curve, and the standard error of estimate (0.204) is somewhat lower than for that curve. While both curves indicate little or no correlation for the period prior to the onset of ripening, both indicate a good positive correlation for the ripening period, the values for acidity in relation to ratio of insoluble to soluble solids indicating that this curve is somewhat more reliable

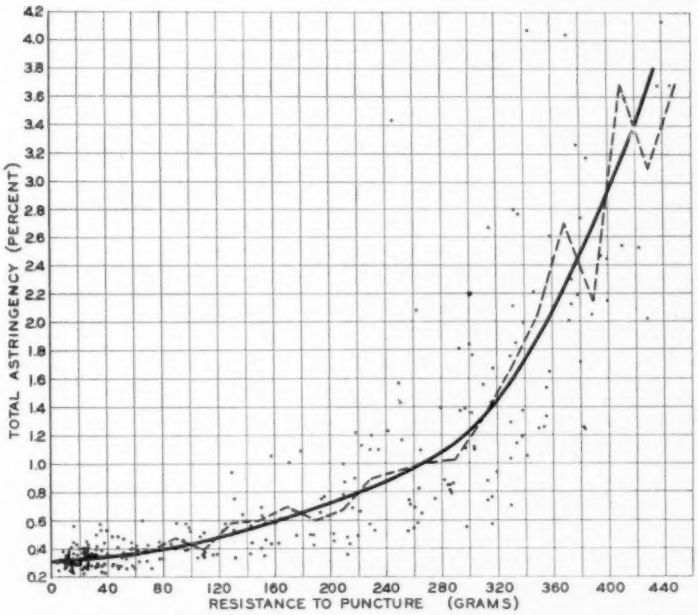

FIGURE 10.—Relationship between percentage of total astringency and resistance to puncture during development and ripening in the strawberry, plotted from data of table 1. The index of correlation is 0.926 and the standard error of estimate 0.459.

than the curve showing the relationship of acidity to resistance to puncture.

TOTAL ASTRINGENCY IN RELATION TO RESISTANCE TO PUNCTURE

Figure 10 presents the results when total astringency is plotted against resistance to puncture. The points fall rather closely about a locus which appears to be a very striking curve. The form of the curve shows that the regression of total astringency on resistance to puncture is constantly changing throughout the development and ripening of the fruit. For low values of the total astringency the resistance to puncture is low; for high values of total astringency the resistance to puncture is high; and there is a very good positive corre-

lation throughout the entire range of values. The index of correlation is 0.926. The index of determination shows that 86 percent of the total variation in astringency may be accounted for by the variation in resistance to puncture. The standard error of estimate (0.459) indicates that only one-third of the values will fall more than 0.459 percent above or below the indicated line of regression. The line is not equally reliable throughout its length, however. It is much more trustworthy in the period of later development and ripening than in the period of early development, as is evidenced by the progressive increase in scatter of the plotted values as the values of the puncture test increase. The reason for this is not clear. It may be due in considerable part to the fact that the method of determination of total

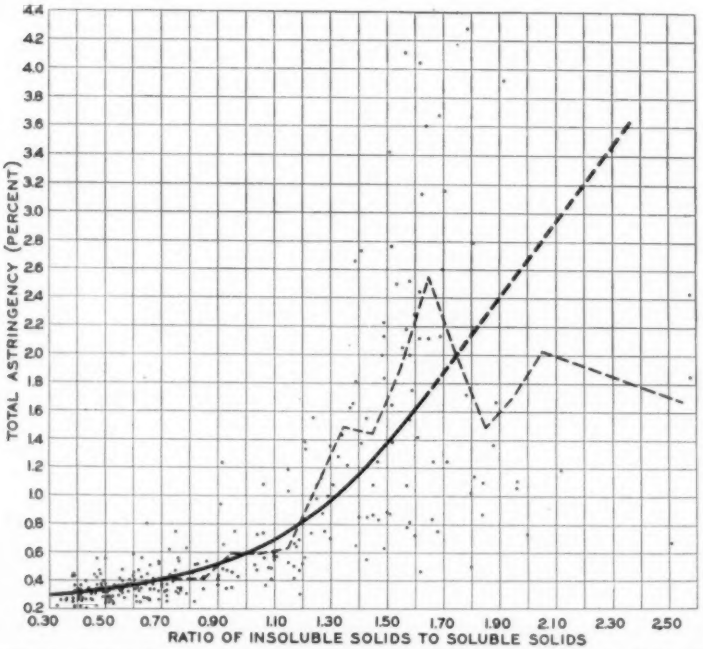

FIGURE 11.—Relationship between percentage of total astringency and ratio of insoluble to soluble solids during development and ripening in the strawberry, plotted from data of table 1. The index of correlation is 0.710 and the standard error of estimate 0.685. The portion of the curve represented by a broken line is questionable because of the relatively small number of samples employed in its determination.

astringency determines a number of related substances that differ in their reducing power for potassium permanganate and that vary independently in amount as the development of the fruit proceeds, which is known to be the case. In part it may be attributed to sampling error and to any or all of the factors already mentioned.

TOTAL ASTRINGENCY IN RELATION TO RATIO OF INSOLUBLE TO SOLUBLE SOLIDS

For comparison with the last curve, the total astringency was plotted against the ratio of insoluble to soluble solids. The results are presented in figure 11.

The form of the curve is very similar to that of the astringency-puncture curve insofar as that portion derived from the later period of development and ripening is concerned. In the case of very immature fruits the number of fruits is small, the scatter of individual fruits is very great, and the line joining group averages is consequently excessively irregular. This may be taken to indicate that the ratio of insoluble to soluble solids as a measure of maturity is not as reliable for very immature fruits as for fruits approaching maturity. There is therefore some question as to whether the form of this portion of the curve, as determined from the number of samples in hand, is what it would be had a larger number of fruits been used. The portion of the smoothed curve which is regarded as questionable is represented on the graph (fig. 11) as a broken line. In the ripening period it is about as good an index of maturity as the puncture test. For the line as a whole the index of correlation is 0.710 and the standard error of estimate is 0.685, with a coefficient of determination of 0.504. These values indicate that the puncture test has considerably greater reliability as a measure of the astringency content than has the ratio of insoluble to soluble solids. The general similarity of the two curves makes the general course of the changes in total astringency fairly clear.

RELATIONSHIP BETWEEN SUGAR CONTENT AND ACID CONTENT

Since the relationship between percentage of acid and percentage of sugar present is a very important factor in determining the palatability of the fruit, it seemed advisable to determine the general relationship between the two constituents in this assemblage of material. In figure 12 the percentage of total titratable acidity is plotted against percentage of total sugars. The scatter of the individual points is very wide, indicating that variations in acid content to a very large extent are independent of the percentage of sugar present. There is a general tendency for titratable acidity to be low when sugars are high, that is, in berries at or nearing maturity, and for acidity to be high when sugars are low, that is in immature or young fruit. The line which represents this relationship is very nearly straight for most of its length, indicating absence of correlation, but rises somewhat in the portion representing very young samples to indicate a low negative correlation. The absence of any pronounced correlation must mean that some factor not accounted for affects one of the constituents without affecting the other. The fact that environmental conditions, which control the rate of accumulation of sugar through controlling the opportunities for photosynthesis, do not have any comparable controlling effect upon the rate of formation or destruction of acids suggests itself as an explanation of the form of the curve.

DISCUSSION OF GRAPHS

Despite the fact that the curves presented in figures 1 to 12 are not rate curves with respect to time, they tend to confirm the general conclusions with respect to the chronological sequence of events in the development of the berry which were stated in the preceding section. The mathematical treatment substantially reinforces most of the statements there made while at the same time it emphasizes the high degree of variability encountered in a large number of samples of different varieties taken over a period of years.

The question as to which of the two methods of measuring stage of maturity that have been applied to the material is the more reliable cannot be answered definitely, since the exact age of the samples was not known. A fairly conclusive answer to the question can be derived from a comparative study of the results of application of the two methods to the data. In all cases in which this has been done, with one exception, the ratio of insoluble to soluble solids appears to be the more reliable of the two. This method, which may be termed a chemical measure of maturity, is least satisfactory when applied to very immature fruits. The resistance of the fruit to puncture, which

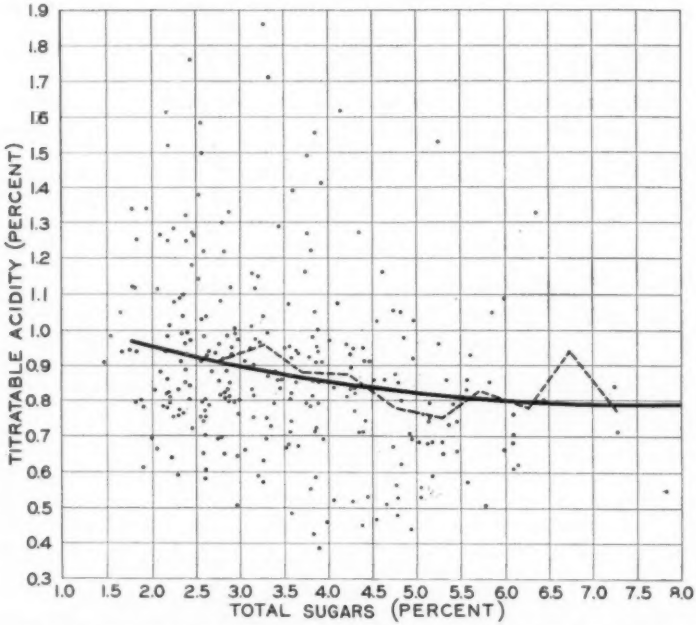

FIGURE 12.—Relationship between percentage of titratable acidity and percentage of total sugars during development and ripening of the strawberry, plotted from data of table 1. The coefficient of correlation is 0.290 and the standard error of estimate 0.247.

is a physical measure of maturity, is very satisfactory for immature fruits, but becomes less reliable as the fruit enters upon the period of ripening. This is true for the particular puncture tester here used; it is, of course, not known what the results would be with other types of testers.

A probable explanation of the failure of agreement between the two measures of maturity in the ripening stage is that environmental conditions at this stage in the life of the fruit exert a considerably greater influence upon the firmness of the berries than upon the relation between insoluble and soluble solids.

PHYSIOLOGICAL CHARACTERISTICS OF INDIVIDUAL VARIETIES

By comparative study of the ripe samples of the several varieties it should be possible to ascertain the degree to which any given variety possesses a definite chemical individuality.

Such a comparison is difficult for the reason that the composition of the ripe fruit of a variety varies considerably from year to year and also from beginning to end of a single crop season, in response to changes in climatic conditions, load of fruit upon the plants, and other varying factors. Since measurements of these factors which would permit any accurate evaluation of their effects could not be made in connection with this study, it can only be assumed that all the varieties were influenced thereby in the same direction and to the same degree and that the averaging together of all the ripe samples of a given variety should give mean values for that variety which are fairly comparable with those obtained in like manner for other varieties. Such average values have been computed and are presented in table 3. The results present a chemical definition or description of each of the varieties in terms of its content of eight constituents.

In order to facilitate comparison of one variety with another, some standard of comparison is desirable. Such a standard, or norm, of entirely arbitrary character has been obtained by averaging together all the data for the ripe samples of all varieties. This treatment permits comparison of any given variety with respect to any given constituent with any other variety or with the average for all the varieties. It does not give any clear concept of the variety as a chemical entity nor does it permit satisfactory comparison of varieties as chemical individuals with one another. In order to make such comparisons it is necessary to treat the data of table 3 in such a manner that the several varieties are presented as entities. Such a method of treatment has been adopted in figures 13 and 14, in which the chemical composition of each of the varieties is represented by a line. The scales upon which the various constituents are plotted were so chosen that the mean values obtained by averaging all varieties fall in a horizontal line across the graph. The composition of each variety was then plotted, and the points on the several scales connected by a line which rises above or falls below the line of general average according as the content of a particular constituent is greater or less than the general average.

TABLE 3.—*Average composition of all ripe samples of each of 12 strawberry varieties*

Variety	Total solids	Soluble solids	Sugars	Insoluble solids	Titratable acidity	Total astringency	Tannin	Nontannin
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Aroma	9.77	6.48	4.63	3.29	0.593	0.365	0.217	0.148
Chesapeake	10.93	7.61	5.88	3.33	.745	.303	.162	.141
Dunlap	10.11	6.33	4.27	3.79	.736	.321	.183	.138
Gandy	11.97	8.35	6.34	3.62	.972	.384	.210	.174
Howard 17	9.95	6.96	5.04	3.00	.780	.289	.177	.112
Klondike	10.63	7.37	4.99	3.26	.969	.378	.238	.140
Missionary	10.89	7.33	5.26	3.56	.772	.389	.217	.172
New York	11.66	8.46	6.53	3.19	.656	.275	.114	.161
Parsons	9.29	6.16	4.49	3.13	.689	.354	.203	.151
Portia	9.08	5.96	4.35	3.12	.586	.280	.138	.142
Progressive	9.73	6.32	4.68	3.41	.628	.272	.152	.120
Sample	9.38	6.27	4.55	3.11	.613	.362	.195	.167
Average	10.16	6.87	5.00	3.29	.705	.319	.178	.141

As a further means of comparing varieties with one another, the ratios between certain constituents, namely, between acid and astringency, acid and sugar, acid and total solids, astringency and total solids, and total solids and sugar, have been calculated for each of the varieties and also for the average of all varieties. These ratios, which are based upon the data of table 3, are brought together in table 4. The mean ratios for all samples form a second standard of reference for facilitating comparisons between varieties.

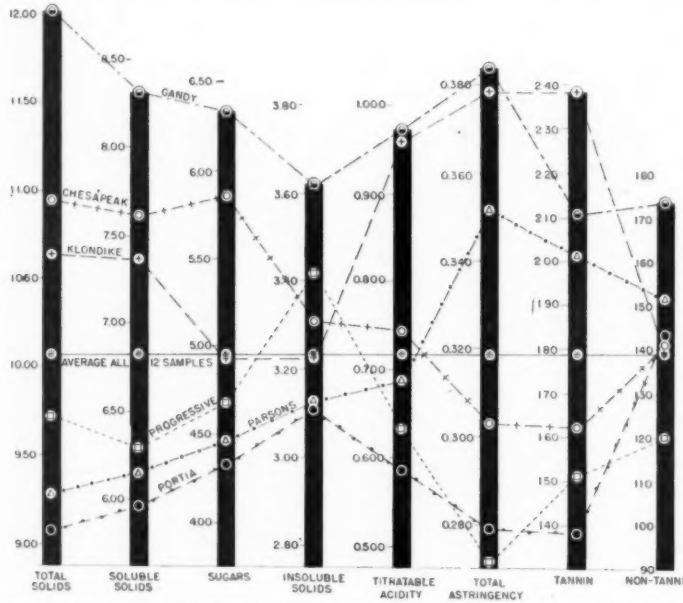

FIGURE 13.—Mean values for total solids, soluble solids, insoluble solids, sugars, titratable acidity, total astringency, tannin astringency, and nontannin astringency in ripe samples of the Gandy, Chesapeake, Klondike, Parsons, Progressive, and Portia varieties, plotted against mean values for the same constituents in all ripe samples of all varieties.

At the same time that the individual characteristics of the several varieties are discussed an attempt will be made to combine the varieties into groups on the basis of similarity of composition. The basis of such grouping is not likeness in absolute amounts of the various constituents, as solids or sugar, in the varieties concerned, but similarity in the relationships existing between the several constituents of the fruit as indicated by the ratios of table 4. Employment of these ratios permits comparison without reference to the absolute amounts of the substances concerned.

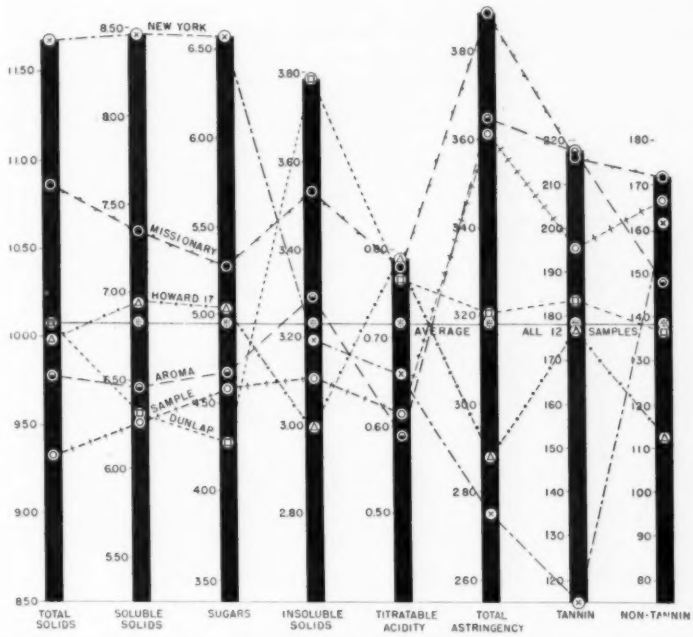

FIGURE 14.—Mean values for total solids, soluble solids, insoluble solids, sugars, titratable acidity, total astringency, tannin astringency, and nontannin astringency in ripe samples of the New York, Missionary, Dunlap, Howard 17 (Premier), Sample, and Aroma varieties, plotted against mean values for the same constituents in all ripe samples of all varieties.

TABLE 4.—*Ratios between various constituents of ripe fruit, derived from data of table 3*

Variety	Astringent substances to acid	Sugar to acid	Total solids to acid	Total solids to astringent substances	Sugar to total solids	Total solids to tannin	Total solids to nontannin substances	Soluble solids to insoluble solids
Aroma	1 : 0.61	1 : 7.8	1 : 16.4	1 : 26.7	1 : 0.47	1 : 45.0	1 : 66.0	1 : 1.96
Parsons	1 : .51	1 : 6.5	1 : 13.4	1 : 26.2	1 : .48	1 : 45.7	1 : 61.5	1 : 1.97
Sample	1 : .59	1 : 7.4	1 : 15.3	1 : 25.9	1 : .48	1 : 48.1	1 : 56.1	1 : 2.01
Portia	1 : .47	1 : 7.4	1 : 15.5	1 : 32.4	1 : .47	1 : 65.8	1 : 63.9	1 : 1.91
Progressive	1 : .43	1 : 7.4	1 : 15.5	1 : 35.8	1 : .48	1 : 64.0	1 : 81.1	1 : 1.85
Missionary	1 : .50	1 : 6.8	1 : 14.1	1 : 28.0	1 : .48	1 : 50.1	1 : 63.3	1 : 2.06
Klondike	1 : .39	1 : 5.1	1 : 10.9	1 : 28.1	1 : .47	1 : 44.6	1 : 75.9	1 : 2.26
Dunlap	1 : .43	1 : 5.8	1 : 13.7	1 : 31.4	1 : .42	1 : 55.2	1 : 73.2	1 : 1.67
Howard 17	1 : .37	1 : 6.4	1 : 12.6	1 : 34.1	1 : .50	1 : 56.2	1 : 88.8	1 : 2.32
Gandy	1 : .39	1 : 6.5	1 : 12.3	1 : 31.1	1 : .53	1 : 57.0	1 : 68.8	1 : 2.30
Chesapeake	1 : .40	1 : 7.9	1 : 14.6	1 : 36.0	1 : .53	1 : 67.4	1 : 77.5	1 : 2.28
New York	1 : .41	1 : 9.9	1 : 17.8	1 : 42.4	1 : .56	1 : 102.3	1 : 72.4	1 : 2.65
All samples	1 : .45	1 : 7.0	1 : 14.4	1 : 31.8	1 : .49	1 : 57.0	1 : 72.0	1 : 2.08

The most important of these relationships is that existing between the amount of acid, astringent substances, and sugars present. The balance or the lack of it between these constituents in a fruit is of primary importance in determining its dessert quality. The relative intensity of the effects of these three groups of substances upon the nerves of taste determine the individual's judgment of the fruit as

acid, sweet, tart, or properly balanced. The conception of the basic character of the fruit thus obtained is supplemented by perception through the organs of taste and smell of the mixture of oils and esters which give the characteristic odor and flavor of the species or variety and permit its recognition among others of its class. No matter how agreeable the individual odor and flavor of the variety may be, it will not be considered desirable unless the balance between sugar, acidity, and astringency is such as to be pleasing. In determining palatability, the absolute amounts of these constituents are of minor importance as compared with the ratios existing between them.

The content of total solids in its relation to these constituents is also a matter of some importance in determining dessert quality of the fruit, as a given quantity of sugar, acid, or astringent substance will be more or less apparent as the total solids associated therewith are large or small in amount.

Considered on the basis of the relations existing between total solids, acid, sugar, and astringent content, the varieties included in the study may be combined into four groups: (1) A low-sugar, low-acid, low-astringency group, consisting of Portia and Progressive; (2) a low-sugar, low-acid, high-astringency group, consisting of Aroma, Parsons, and Sample; (3) a medium-sugar, high-acid, medium-astringency group, made up of Gandy, Missionary, Klondike, Dunlap, and Howard 17; and (4) a high-sugar, low-acid, low-astringency group, consisting of New York and Chesapeake. These groups will be discussed in some detail.

LOW-SUGAR, LOW-ACID, LOW-ASTRINGENCY GROUP

Portia and Progressive show a considerable degree of likeness in composition as regards the absolute amounts of their several constituents. Both are low in total solids and in all the constituents of total solids, but notably so in total astringency and its components. As compared with the line of general average (fig. 13), they form a group characterized by low values throughout with especially low astringency. Reference to the table of ratios shows that in respect to the ratios of acid to solids, acid to sugar, and solids to sugar, they do not differ greatly from the second group or from the general average. In the ratio of acid to astringency they are much higher and in that of astringency to total solids much lower than the second group, indicating a materially lower level of astringency in relation to the general level of other constituents than prevails in Aroma, Parsons, and Sample. Their ratios of acid to astringency and to sugar and of astringency to solids are not so low as is the case in New York and Chesapeake, so that their sweetness to taste is not so pronounced as in these varieties.

Progressive is below the general average in every constituent determined except insoluble solids. It is the lowest of the 12 varieties in total astringency, and has lower nontannin astringency than any other variety except Howard 17. In general composition it resembles Portia, but is somewhat higher in total insoluble and soluble solids, sugar, and tannin, and somewhat lower in total astringency and in nontannins. Its low acidity and very low astringency result in a degree of sweetness to taste exceeding that of many berries of considerably higher sugar content.

Portia is lowest of all the varieties in total solids, soluble solids, and acidity. Howard 17 is very slightly lower in insoluble solids, Dunlap is slightly lower in sugar, and Progressive and New York are lower in total astringency. Considered in relation to its other constituents, the insoluble solids and nontannins of Portia are rather high, but its low acid and total astringency ratios give it a sweetness to taste, as in the case of Progressive, out of proportion to its actual sugar content.

LOW-SUGAR, LOW-ACID, HIGH-ASTRINGENCY GROUP

The three varieties Aroma, Parsons, and Sample are very similar. In comparison with the line of reference, or general average (figs. 13 and 14), they are very low in total solids, soluble and insoluble solids, sugar, and acidity, but are quite high in total astringency as a result of a fairly high content of both tannins and nontannins. Reference to the table of ratios brings out the fact that there is also a close resemblance between them in the ratios existing between their constituents. The ratio of acid to astringency is 1 to 0.5 or 0.6; the ratio of astringency to solids approximates 1 to 26, indicating a relatively higher astringency in relation to acidity and to solids than is found in any of the other varieties. The ratio of acid to sugar is slightly above the general average in Parsons, slightly below in Aroma and Sample. The acid-solids ratio is above the general average in Parsons and fairly close to the average in the others. The ratio of solids to sugar is practically identical in all.

Aroma is low in total solids and all components of total solids except astringent substances. It rather closely resembles Parsons in composition, but is slightly higher in absolute amounts of all constituents except acid and nontannin. Sample is considerably below the line of general average in all constituents except astringent substances, in which it is quite high. It is almost identical with Parsons in total solids, soluble and insoluble solids, and sugar, somewhat lower in acidity, and higher in total astringency. It is quite high in nontannin astringency, being exceeded only by Gandy and Missionary in this respect.

Parsons is slightly more acid than Aroma and Sample and slightly less astringent. Like them, it is quite low in total solids, insoluble and soluble solids, and sugar, a fact which determines its place here rather than in the next group. Hedrick (*14*) characterizes Aroma and Parsons as "pleasantly sprightly" and Sample as "subacid to somewhat sprightly." He terms Portia and Progressive "subacid." These five varieties differ only slightly in their ratios of acid to sugar or to solids, but Portia and Progressive have considerably lower astringency, both absolute and relative, than the others. The term "pleasantly sprightly", as used by Hedrick, evidently connotes the presence in the fruit of such a balance between astringency, acid, and sugar as is pleasing to the palate. With reduction in the amount of astringents present, fruit with the same acid-sugar ratio is subacid, tending toward insipid.

MEDIUM-SUGAR, HIGH-ACID, MEDIUM-ASTRINGENCY GROUP

Gandy, Missionary, Klondike, Dunlap, and Howard 17 (Premier) in that they have high ratios of acid to solids and to sugar, while their ratios of astringency to solids are intermediate between those of

the first and second groups. They are consequently characterized by a sharply acid, distinctly astringent flavor which is subdued but not lost when the fruit is preserved with the addition of sugar.

Missionary is in some respects intermediate in its chemical characters between the last-mentioned group and the present one. It is well above the general average and consequently markedly above the last group in total solids and in practically all constituents of total solids, its total astringency exceeding that of any other variety. In its absolute amount of solids, sugars, and other constituents it is like other members of this group. Examination of the table of ratios shows that in acid-astringency, acid-sugar, acid-solids, and astringency-solids ratios it is almost identical with Parsons. Parsons is a little higher in its acid-sugar and acid-solids ratios than the other members of its group, while Missionary is a little lower in its acid-sugar and acid-solids ratios than the other members of the present group. Parsons and Missionary are consequently intermediate between the low-acid, high-astringency group and the high-acid, medium-astringency group. Missionary is characterized by Hedrick (*14*) as quite tart, a designation which takes account of its high astringency.

Klondike is considerably above the general average in its total and insoluble solids, is average in sugar, very slightly below average in insoluble solids and nontannins, and markedly high in acidity, total astringency, and tannin. Its high acid-astringency and acid-solids ratios make it relatively the most acid berry of the entire group, despite the fact that its sugar content is up to the general average of all varieties. Hedrick terms it "sprightly to acid."

Dunlap is unique among the varieties studied in that while its total solids, acidity, total astringency, and components of total astringency are all practically on the line of general average, its insoluble solids are the highest found in any variety and its soluble solids and sugars are close to the minimum values found in Portia and Parsons. Its ratio of solids to sugar is the highest noted in the 12 varieties, and its ratio of acid to sugar is exceeded only by that of Klondike. In consequence of its high acid-sugar ratio, it has a greater apparent acidity than other berries of equal absolute acid content but of higher sugar content, such as Chesapeake and Missionary. Hedrick's characterization of the fruit as "mild" is somewhat surprising in view of the chemical data.

Howard 17 (Premier) more closely approximates the general average in the amounts of all its constituents than does any other variety. Total solids, soluble solids, sugar, and tannins fall practically on the general average line; acidity only slightly above it. Insoluble solids and nontannins are the lowest found in any of the varieties, and total astringency is only slightly above the minimum values found in Progressive, Portia, and New York. In the ratios between its constituents, Howard 17 is very much like Gandy, having almost identical acid-astringency, acid-sugar, and acid-solids ratios. All these are higher than average, so that the berry is a distinctly acid one. Hedrick terms Howard 17 "pleasantly sprightly."

Gandy is outstanding in its high content of total solids and of all constituents of the total solids. It is equaled by no other variety in total solids, acid, and nontannins, is exceeded in soluble solids and

sugar only by New York, and in tannin by Klondike, Missionary, and Aroma. As compared with the general average of all samples, Gandy is high in all constituents but especially so in total solids, acidity, and astringency. Its similarity to Howard 17 in the ratios between its constituents has already been noted. Its ratio of solids to sugar, 1 to 0.53, is lower than the average, which has the effect of increasing the sweetness of the fruit to taste. Hedrick classes Gandy as "briskly subacid."

HIGH-SUGAR, LOW-ACID, LOW-ASTRINGENCY GROUP

The New York and Chesapeake present a combination of high solids and sugar content with very low ratios of acid and astringency to solids and especially to sugar. This gives both berries a pronounced sweetness which is agreeable in the fresh condition but which renders them rather characterless and lacking in acidity and sprightliness when preserved with the addition of sugar. Both berries have low ratios of solids to sugar, which further intensifies the sweetness of the fruit.

Chesapeake is high in total and soluble solids and in sugar, being exceeded in the amounts of these constituents only by Gandy and New York. It is very slightly above the general average in insoluble solids and acidity, and somewhat below it in total astringency and tannin. Its ratio of acid to sugar is rather low, but it is preserved from being insipidly sweet by rather high acid-astringency and acid-solids ratios. Hedrick classifies it as "mildly acid."

New York is unique in that it departs more widely from the line of general average in its composition than does any other variety. In total solids it is exceeded only by Gandy, and in soluble solids and sugars it exceeds all others. Its insoluble solids and acid content are below the general average, and its total astringency and tannin content are the lowest found in any of the varieties. Its nontannin content is well above the general average, being exceeded only by Gandy, Missionary, and Sample. Of all the varieties studied it has the lowest ratios of acid to sugar, astringency and tannin to solids, and solids to sugar. This makes it a variety of outstanding sweetness to taste. Hedrick terms it "mildly subacid."

In conclusion, it should be noted that the foregoing results were obtained from fruit grown in one locality only, and that there is a possibility that repetition of the work in a more northern or southern locality would result in an alteration of the relative positions of some of the varieties. These results can be said to hold strictly only for the vicinity of Washington, D. C. There is need for further work upon the effect of various soils and different environmental complexes upon the composition of the strawberry.

CHEMICAL AND PHYSICAL CHARACTERS OF THE STRAWBERRY IN RELATION TO ITS UTILIZATION

The varieties used in this study include all the older and more widely cultivated commercial sorts. They therefore represent the result of selection definitely directed toward the production of fruit of a character adapted to market and shipping purposes, and presumably conform rather closely to the general conception on the part of breeders and growers as to what a desirable commercial berry should be.

These varieties present very great diversity in the degree of their adaptability or suitability for preservation by canning, freezing, or other means, and yield products differing greatly in appearance and palatability when so treated. The reason is that the chemical and physical characters which must be possessed by a berry if it is to yield a satisfactory canned, frozen, or preserved product are in part distinct from those that are acceptable in a commercial or dessert fruit.

Some characters which are unobjectionable or even desirable in a commercial berry are distinctly undesirable in a fruit to be used for preserving purposes. Conversely, some characters which are indispensable to the making of a high-grade preserved product are not required and may even be objectionable in a dessert fruit. The analytical data supply a measure of some of these characters; others show no correlation with any facts brought out by the analyses.

In the following paragraphs an attempt is made to state the characteristics of an ideal berry for preservers' use, to check the different varieties against this ideal, and to correlate chemical and physical composition with adaptability to preserving purposes.

FIRMNESS OF FLESH

In order to be suitable for preservers' use, a strawberry must have a texture of flesh that will enable it to withstand heating in sirup, or freezing and subsequent thawing, without breaking down and losing its form in the process.

Of the varieties herein employed, Klondike and Gandy retain their form under preservative treatments in a higher degree than do the others. The only chemical character of these berries with which this property of resistance to heat appears to be correlated is their high absolute acidity, approximating 1 percent, and their high ratio of acid to other constituents. Whether the high acidity of these varieties is a coincidence or has a causal relation to their behavior in cooking can only be determined from more extensive studies on a wide variety of material. There is clearly no correlation between firmness under these treatments and amount of total solids or insoluble solids or ratios of insoluble to soluble or to total solids.

The puncture tester employed in the present work determined the resistance of the fruit to penetration by a small plunger, 0.032 inch in diameter. At a given stage of ripeness, as red ripeness, all the varieties showed practically equal resistance to puncture, no significant differences being observed among them. Resistance to puncture by a small plunger is definitely correlated with stage of maturity, as shown in a preceding section, but does not show any correlation with the resistance of the fruit to deformation or crushing under pressure or with the amount of softening that will occur when the fruit is heated. The amount of softening and breaking to pieces occurring in the course of preservative treatment cannot be predicted with certainty from the characterizations of varieties in horticultural descriptions as "soft", "moderately firm", and the like, since varieties classed as "soft" and "firm" may break down to the same degree in preserving.

COLOR

The character and degree of change in color occurring in the course of preservative treatment are quite important in determining the

desirability of a berry for preservers' use. An ideal berry for preserving would be one that would retain the color of the fresh fruit unchanged through the preservative processes. No existing berry does this, but both the degree and the character of the change in color differ greatly in different varieties. One of the objects of the present study was to ascertain whether any definite relationship exists between chemical composition and the alteration and loss of color in the process of preservation. The results have been negative, but a brief statement of some of the observed facts may be made.

The pigment of the strawberry shows the general behavior of the anthocyans, but as its chemical composition has never been determined it is not known whether it is a single pigment or a mixture. Because of its reducing properties it is included in the substances designated as nontannin astringents, along with varying amounts of other and unknown substances which reduce potassium permanganate. There is consequently no relation between the amount of the nontannin astringency and the apparent intensity of color of the fruit. Progressive, Missionary, and Sample are varieties that are deeply colored both at the surface and throughout the flesh to an approximately equal degree. Missionary and Sample have the maximum amounts of nontannins found in the series, whereas Progressive has very slightly more than the minimum found in Howard 17. The other varieties studied differ widely in their apparent pigment content without any relation to their nontannin values.

Darrow and Waldo (*9*) have studied the color changes occurring in a number of strawberry varieties, including Aroma, Chesapeake, Klondike, Howard 17, Missionary, and Dunlap, and in a number of their own selections. Their colored plate (*pl. 2*) shows that considerable alteration of color occurs when the ripe fruit is picked and allowed to stand for a few days at summer temperature. In the case of Howard 17, Missionary, and Dunlap the change of color is toward purple; in Aroma, Chesapeake, and Klondike it is toward dusky reddish brown. Similar changes occur when the fruit is allowed to become overripe on the plant.

Culpepper and Caldwell (*5*) have reported that in the course of canning experiments with about 200 varieties and strains of strawberries they encountered several types of behavior of the pigment of the berry after canning. In the type of most frequent occurrence the original red color became converted to some shade of brown or brownish red when the fruit was heated either in glass or in metal cans. This was attributed to isomerization of the pigment to a colorless form together with browning due to the oxidation of tannin. In another type the change in color was a fading, or lessening in intensity, of the red color with no pronounced browning, which would occur if isomerization of pigment without oxidation of tannin had taken place.

In the varieties herein studied there were very considerable differences in the degree and character of the color changes of the canned product. In Chesapeake, Gandy, Howard 17, Missionary, Sample, and Progressive, the outstanding change was a fading, or lessening in intensity, of the original color, apparently due to conversion of some of the pigment to the colorless form. This was accompanied by a variable but never extreme degree of browning. In Aroma, Portia, Parsons, and Klondike the original color was deepened to a dark

brownish red, very similar in appearance in all. In Dunlap and New York there was only slight fading and very little browning.

These results cannot be correlated with any chemical characters brought out by the present study. The group in which pronounced fading under heat occurs includes the deeply colored, highly acid, highly astringent Gandy, together with berries of medium to low acid and astringent content. The group in which pronounced browning occurs contains the highly acid, rather astringent Klondike with others of low acidity and astringency. Dunlap and New York, in which a minimum of change of either type occurs, are quite unlike in chemical characters. It is consequently impossible to correlate behavior of pigment with any type of chemical composition. Understanding of the behavior of pigments of the fruit must await studies of its chemical composition and properties.

PERSISTENCE OF FRESH FRUIT FLAVOR

The palatability of a preserved berry is determined to a very considerable extent by the degree to which the consumer recognizes in it persistence of the flavor of the fresh fruit. This flavor is due partly to essential oils and esters and partly to the balance between sugar, acidity, and astringency in the product. In the process of preservation very considerable quantities of sugar are added to the fruit in the form of sirup. The resulting interchange with the tissue fluids of the fruit brings about considerable change in the flavor of the fruit insofar as the balance between sugar, acidity, and astringency is concerned. As sugar content is increased, acidity and astringency are decreased by dilution with the neutral sirup, and there is also some actual loss of astringent substances through oxidation or destruction by heat in the course of application of the preservative treatment. The extent of these changes will depend upon the amount and concentration of the sirup used and other varying factors, but the direction of the changes will always be toward loss of the balance and character of the fresh fruit and its replacement by a bland, insipid sweetness.

The standards of quality applied to commercial berries are based upon the appeal that the fruit makes when eaten in the fresh condition. In fruit to be so eaten, sweetness is a primary consideration, and a high ratio of sugar to total solids with medium to low proportions of acidity and astringency is desirable. Consequently, the trend in selection of berries for commercial cultivation has tended to eliminate strains that are too high in acidity or astringency, or both, to be agreeable when eaten out of hand. The result is that when a desirable dessert fruit is preserved in sirup, it may become little more than a vehicle for sugar. In order to produce a preserved product which will be strongly suggestive of the fresh fruit flavor it is necessary to balance the added sugar by employing fruit of considerably greater acidity and astringency than would be acceptable in a dessert fruit. Since breeders have heretofore discarded such strains as they have appeared, this necessarily means that in the future attention will have to be given to the development of varieties specifically adapted to preserving purposes through selection of seedlings possessing desirable chemical as well as physical and horticultural characters.

With all the varieties herein studied, some improvement in the balance and flavor of the preserved material was obtained by employing fruit at the red-ripe stage as compared with fully ripe fruit. The obvious reason is that sugar content is increasing and acid and astringent content are decreasing from the stage of red-ripeness onward to full ripeness. These changes result in a decided improvement in dessert quality but entail a very marked decline in character and balanced flavor of the canned or frozen product.

Of the varieties herein studied, the low-sugar, low-acid, low-astringency group, Portia and Progressive, and the high-sugar, low-acid, low-astringency group, New York and Chesapeake, are most seriously lacking in the characters requisite to the making of high-grade preserved products. When preserved by the addition of sugar they become bland, pleasantly flavored, with little or no varietal flavor or character. Whatever other characters they may have which may be considered desirable in a berry for preserving purposes, these varieties serve chiefly as vehicles for conveying sugar.

The low-sugar, low-acid, high-astringency group, Aroma, Parsons, and Sample, yield preserved products of better balance and more character than those just listed. While somewhat deficient in acidity, their relatively high astringency prevents conversion of the product to an insipidly sweet one when preserved in sirup.

The group offering greatest possibilities for preservative purposes, insofar as composition is concerned, is the medium-sugar, high-acid, medium-astringency group, made up of Gandy, Missionary, Dunlap, Howard 17 and Klondike. Of all the varieties herein studied, Klondike is preferred for frozen packing for use in ice cream, etc., and is probably most generally employed for canning, with Gandy ranking next (*10*). Both combine fairly high acidity and astringency with other desirable characters, including deep-red color extending well into the flesh, and a firmness of texture which prevents cooking to pieces or collapse of the fruit in preserving. Missionary is somewhat similar to Klondike in composition, but is less firm in texture. Dunlap is also somewhat soft as compared with Klondike. Howard 17 is only moderately firm and has fairly good color, but its low astringency makes its preserved products somewhat lacking in sprightliness and balance.

Many or most of the varieties herein studied are rather harshly astringent when under-mature but become less so as they ripen because of the rather rapid reduction in amount of the total astringency. The total astringency is the sum of two components, true tannins and nontannins, the latter consisting of anthocyans and associated substances having reducing properties. The true tannins considerably exceed the nontannins in the immature fruit but decrease rather rapidly during ripening, the nontannins meanwhile increasing considerably. In the ripe fruit the amount of true tannins is still somewhat in excess of nontannins except in two varieties: Portia, in which the two are practically identical in amount; and New York, in which nontannins exceed true tannins by 50 percent. While both tannin and nontannin contribute to the astringency of the fruit, the true tannins are apparently much more important in determining flavor.

While tannin is a highly desirable constituent, in that it contributes balance and sprightliness to the flavor of the preserved fruit, its presence offers considerable difficulty in canning or freezing. It oxidizes readily upon exposure to the air and more rapidly upon heating, with the production of a brown discoloration. Since the tissues of the fruit contain considerable quantities of air, which is removed with difficulty,[6] the prevention of brown discoloration in canning and freezing has not been successfully accomplished. It is less rapid and intense in the more acid Klondike and Gandy than in varieties which are lower in acidity, and the experimental addition of an organic acid to the sirup in which fruit of the less acid varieties is canned or frozen results in distinct lessening of the brown discoloration. Consequently, berries that combine high tannin and acid content with a high specific gravity may show less tendency to browning than do berries with low acid and tannin content but with low specific gravity and a high percentage of air in the tissues.

SUMMARY

Studies of the physiological changes in the strawberry fruit occurring during its development were carried on for 4 seasons on 12 varieties, including all the more important commercial sorts of the Eastern States. Samples were collected at intervals of 5 to 7 days, beginning at a time when the petals of the earliest flowers were still attached and continuing until most of the crop had reached full soft ripeness. At the later samplings, material representing all the fruit on the plants was separated into 2 or 3 lots on the basis of size or, in the later stages, of color.

The earliest samples secured were characterized by very marked firmness and by high solids content. As compared with later stages of development, the young fruit at the stage of petal fall has maximum resistance to puncture, maximum total and insoluble solids, and maximum content of material which reduces potassium permanganate (total astringency). Titratable acidity and soluble solids are fairly high but not maximum. Sugars are small in amount and usually make up only 30 to 40 percent of the soluble solids. Considerable sucrose is occasionally present, but free reducing sugars usually make up 60 to 90 percent of the total amount.

On entering upon the phase of rapid enlargement, the fruit decreases considerably in its resistance to puncture. The outstanding chemical change accompanying the onset of rapid growth is a progressive increase in water content. The decrease in total solids is due chiefly to a decrease in insoluble solids, and in smaller part to a decrease in soluble solids. There is a very pronounced decrease in materials that reduce potassium permanganate. Sugar content remains practically stationary or decreases slightly, while active acidity and titratable acidity show an increase.

The period of growth up to the stage of loss of chlorophyll, or beginning of the whitening stage, is one of progressive decrease in resistance to puncture and in total solids, insoluble solids, and astringent

[6] Culpepper and Moon (7) found that in 36 varieties and strains of strawberries tested the specific gravity of the fruits ranged between 1.008 and 0.922, and the percentages of air by volume in the tissues between 3.3 and 11.3. For Missionary the figures were: Specific gravity 0.965, air 7.2 percent; for Portia, 0.947, 8.3; for Howard 17, 0.946, 8.5; for Progressive, 0.946, 8.8; for Klondike, 0.935; for Dunlap, 0.937; for Aroma, 0.932. They point out that berries of high specific gravity are generally more desirable for canning than those with lower specific gravity, because of the greater tendency toward pinholing of the can in the latter.

materials. Titratable acidity and total sugars usually increase slightly but may fluctuate irregularly with little change. Soluble solids may decrease slightly or show practically no change. In these results the irregular variations in soluble solids and in sugars are in part due to day-to-day variations between rate of absorption of water and rate of formation and transport of sugar into the fruit, and in part to sampling errors.

The stage of whitening is very definitely characterized chemically. At this stage the fruit attains the maximum water content present in its entire life history, together with maximum titratable and active acidity. Soluble solids, which have declined or remained relatively stationary up to this time, now begin to increase, chiefly as a result of increase in total sugars. Insoluble solids, which up to this time have declined fairly rapidly, enter upon a slower rate of decrease. Astringent materials, which have heretofore decreased rapidly, enter upon a much slower and quite irregular decline. Resistance to puncture has decreased to between one-third and one-fourth that found at the initial sampling.

Transition from the stage of whitening to full ripeness is accompanied by a very rapid decrease in resistance to puncture. Total solids increase chiefly as a result of increase in total sugars, which more than compensates for the continuing decrease in insoluble solids. Sugars make up 70 to 80 percent of the soluble solids and about 50 percent of the total solids of the ripe fruit, and consist chiefly of reducing sugars. Titratable acidity declines rapidly; total astringency declines slowly from whitening to full ripeness.

The chemical composition of the crop at any stage in its development or at ripeness is to a very high degree determined by the relative activity of two opposed processes, the absorption of water and the accumulation of sugar. The growth of the fruit is accompanied by progressive hydration, which tends to reduce the percentage content of all the solid constituents. At the same time sugars are being received from the leaves, which tends to increase the solids content. The rate at which hydration occurs is determined by the initial soil moisture and the amount of precipitation; the rate at which transport of sugar to the fruit occurs is governed by temperature and amount of sunlight. Both processes are consequently controlled by environmental conditions. Alternations of conditions that favor one or the other process during growth produce temporary fluctuations in composition of the fruit. Normally the accumulation of water is the dominant process up to the whitening stage; from that time onward accumulation of sugar becomes the dominant process, but the amount of these changes may be altered by external conditions.

These general statements with respect to the chronological sequence of events in the course of development of the fruit are substantially reinforced by a statistical treatment of the analytical data, in which all the 278 samples were considered as one class and in which determinations were made of degrees of correlation between a number of the constituents of the fruit and two different indices of maturity. One of the indices employed, the resistance of the fruit to puncture, or penetration by a needle, is a physical measure of maturity, while the other, the ratio of the insoluble solids of the fruit to the soluble solids, is a chemical measure of maturity. The two measures of maturity have a coefficient of correlation of $+0.917$, indicating a very

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good agreement. Agreement is less perfect with extremely young fruit than with fruit in the later stages of development.

The coefficient of correlation of insoluble solids with resistance to puncture is +0.882. The index of correlation of soluble solids with resistacne to puncture is 0.641, and the line of regression is a curve indicating positive correlation when puncture-test values are high, and negative correlation when puncture-test values are low. Total solids plotted against resistance to puncture showed a distinct correlation between the two sets of values, and calculations of the coefficient of correlation gave a value of 0.754. The index of correlation for total solids with the ratio of insoluble to soluble solids is +0.884; the coefficient of correlation of total sugars with resistance to puncture is 0.817, the correlation being negative; the coefficient of correlation of total sugars with the ratio of insoluble to soluble solids is 0.871 and is also negative. In the case of fruit that has entered the ripening stage, the correlation of both total solids and total sugars with the ratio of insoluble to soluble solids is much closer than their correlation with resistance to puncture. Titratable acidity was found to have an index of correlation of 0.494 with resistance to puncture and of 0.547 with the ratio of insoluble to soluble solids. The forms of the curves indicate little or no correlation for the period prior to onset of ripening, but very good positive correlations with both in the ripening period, that with the latter being somewhat higher. The coefficient of correlation of total astringency with resistance to puncture is 0.926; that with the ratio of insoluble to soluble solids is 0.710, the forms of the curves indicating greater reliability of resistance to puncture as a criterion of maturity in the case of very young fruits. There is a low but significant negative correlation between sugar content and acid content.

As a basis for making comparisons of the chemical composition of the varieties and determining the degree to which varieties have definite chemical individualities, the average composition for all the ripe samples of each variety was determined, and also the grand average for all ripe samples of all varieties. The ratios between certain constituents, namely, acidity and astringency, acidity and sugar content, acidity and total solids, astringency and total solids, and total solids and sugar, were then determined for each of the varieties. Comparisons of these ratios permit grouping of varieties of like composition without regard to the absolute amounts of the constituents present. So considered, the varieties form four groups: (1) A low-sugar, low-acid, low-astringency group, consisting of Portia and Progressive; (2) a low-sugar, low-acid, high-astringency group, made up of Aroma, Parsons, and Sample; (3) a medium-sugar, high-acid, medium-astringency group, consisting of Dunlap, Howard 17, Gandy, Klondike, and Missionary; and (4) a high-sugar, low-acid, low-astringency group, consisting of Chesapeake and New York.

The chemical characteristics of each of these groups as they affect the adaptability of the fruit to various preservative treatments are considered in some detail. None of the varieties studied is especially well adapted to preservers' use, primarily for the reason that the ratios of acidity and astringency to sugar content which are acceptable in a fresh fruit are too low to permit retention of balanced flavor and palatability when the fruit is preserved with sugar. Of the several groups, the medium-sugar, high-acid, medium-astringency group most nearly approaches the type of chemical composition desirable in a berry for preserving purposes.

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THE TREND OF ORGANIC FOOD RESERVES IN ALFALFA ROOTS AS AFFECTED BY CUTTING PRACTICES[1]

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INTRODUCTION

For 20 years experimental work relating to the time and frequency of cutting alfalfa (*Medicago sativa* L.) has been conducted at the Kansas Agricultural Experiment Station. The purpose of the earlier experiments was to determine the relation of cutting practices to the yield and the quality of hay. It was thought that frequent cutting stimulated growth and increased the yields. It was soon found, however, that such treatment usually resulted in injury to the stand and decreased yields. Later it was shown that if the alfalfa was not cut too frequently the stands could be maintained longer and the yields increased. Certain data from these experiments also indicated that the latter part of the growing season is the critical period insofar as cutting practices are concerned. It seemed desirable, therefore, to conduct new experiments to verify this conclusion and to study the effect of various cutting practices. Since recent experiments in Kansas and elsewhere have indicated a relation between the time and frequency of cutting and the organic reserves stored in the roots, it seemed advisable to determine the trend of these reserves throughout the season and also the effect of cutting practices on the storage of such reserves. The experiments reported here were undertaken to secure information regarding these points.

REVIEW OF LITERATURE

The literature dealing with the time and frequency of cutting in relation to permanence of stand, yield, and organic reserves has been reviewed by several writers, and an extensive discussion of earlier contributions seems unnecessary. The work of Salmon et al. (*17*)[3] clearly showed that alfalfa is affected by cutting treatments. Graber et al. (*6*) showed that the vigor and productivity of alfalfa is greatly reduced and the mortality rate of the plants increased by frequent and early cutting. Aldous (*2*), working with pasture plants, found that the organic reserves of perennial herbaceous plants decrease in the spring until the top development reaches a certain stage, after which they accumulate and are stored in the roots.

In studies with grasses, Graber (*5*) found that certain practices which interrupted photosynthesis also limited subterranean development, increased the susceptibility to drought and winter injury, and gave other indications of a weakened condition of the plant. Arny (*3*), in his work with the underground parts of five perennial weeds, found

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[3] Reference is made by number (italic) to Literature Cited, p. 708.

that the carbohydrate and nitrogenous reserves vary somewhat during the season and that many plants are weakened or killed by certain cutting practices. Previous work by the writer (*7*) with pasture weeds indicates that if the photosynthetic parts are removed when the reserve supply is low there is a tendency to starve the plant. Kraus and Kraybill (*10*), Harvey and Murneek (*9*), Murneek (*12*), Albert (*1*), Nelson (*13*), Pierre and Bertram (*15*), Reid (*16*), and others have made distinct contributions to the study of organic reserves.

METHODS AND MATERIAL

The studies reported here are based on two field experiments, the first of which was started in the summer of 1929 in a field of alfalfa that had been seeded the previous fall on a dark alluvial soil of high fertility, and the second in 1931 on a soil of the same type. In the first experiment there were 9 duplicated treatments, differing with respect to time or frequency of cutting, and 6 check plots. The treatments were arranged to give growing periods of various lengths after the last cutting in the fall, thus providing different degrees of winter protection.

Root samples for chemical analyses were taken at the beginning of the experiment, which was the third cutting in 1929, and thereafter at the time the plots were cut until the spring of 1932, except that samples of the first and second cuttings in 1931 were not taken. Root samples were also taken in the late fall and early spring while the plants were dormant. In sampling, all plants were dug in a representative 0.0001-acre area, measured by a hoop. The area was selected from a part of each plot reserved for that purpose, samples being taken from duplicate plots.

The primary objective of the second experiment was to determine more completely than was possible in the first experiment the fluctuations in carbohydrate and nitrogen reserves throughout the season, the relation of these fluctuations to cutting practices, and the effect of the past season's treatments on yields. In 1931, there were 4 variously treated plots, a fifth being added in 1932 and designated as plot 1. Single plots 30 feet wide and 145 feet long were used. In 1932, plot 1 was cut 4 times, each time when in full bloom. In 1931, and 1932 plot 2 was cut first in the bud stage and thereafter 3 times in full bloom; plot 3, twice in the bud stage and twice in full bloom; plot 4, 3 times in the bud stage and once in full bloom; and plot 5, 4 times, each time when in the bud stage. In the fall each plot was divided lengthwise into three divisions designated as *a*, *b*, and *c*. These were treated as follows: On *a* the top growth was removed at the time it ceased to increase in quantity, on *b* the top growth was removed after it had all been killed by freezing, and on *c* the top growth was allowed to remain on the plots for winter protection. It seemed desirable to eliminate the cumulative effect of the treatments; therefore new plots were established each year.

Root samples representative of all plots treated similarly previous to sampling were obtained at weekly intervals. For example, the samples from plot 1 taken from April 2 to May 21, 1932, are representative of plots 2, 3, 4, and 5, as they were all treated alike up to the later date. Likewise, the samples taken on plot 2 between May 21 and June 21, 1932, are representative of plots 3, 4, and 5. Chemical analyses were based on 100 roots selected at random.

The roots in both seasons were analyzed for total carbohydrates and total nitrogen, previous studies having indicated that the effect of the different treatments on root reserves could probably be measured in this way. Immediately after digging, the root samples were cut into 8-inch lengths and washed. Each sample was then cut into pieces approximately 1 inch in length, placed in a glass jar, covered with 95-percent alcohol, sealed, and stored for future chemical analysis. In preparing the roots for analysis the alcohol was drained off and the roots were allowed to dry, after which they were coarsely ground and again placed in the alcohol. They were allowed to absorb the alcohol and were then dried again, the alcohol being evaporated off at approximately 80° C. During the last drying the samples were mixed well with the material in the alcohol by stirring occasionally. The dried samples were again ground until 98 percent or more of the material passed through a ½-mm sieve. Analyses of total carbohydrates and nitrogen were made of this finely ground material. With this method of drying and incorporating the alcoholic extract with the roots, only one determination for total carbohydrates or nitrogen was necessary for each sample. The Kjeldahl method was used for the determination of total nitrogen. In making the carbohydrate determinations a 3-g sample was hydrolyzed and the reducing power of an aliquot portion was determined in duplicate. The sugar determination was made by the cuprous titration method as developed by Shaffer and Hartmann (*18*), and the amount of carbohydrates was calculated as dextrose from the Munson-Walker tables (*4*). Results are reported on a dry-weight basis.

EXPERIMENTAL RESULTS

EXPERIMENT 1

Data secured from the first experiment are given in table 1. It will be noted that at the fall dormant period the differences in total carbohydrates and nitrogen due to the different cutting practices were slight, except in the more severe treatments of plots 14 and 29, which were clipped every 10 days after the last cutting and for which the total carbohydrates and in most cases the nitrogen were consequently less than for any other plot. The difference in carbohydrates ranged from 3 to 10 percent. Plots 12 and 27, which were cut in the bud stage throughout the season, seemed to run somewhat lower at the fall dormant period in carbohydrates than those cut less frequently, but the differences are not great nor are they consistent. Plot series 1, 2, 16, and 17, which was cut but once, and series 4, 5, 19 and 20, and 15 and 30, which were cut but twice during the season, appeared to contain somewhat more carbohydrates and nitrogen than those cut more frequently, but here again the differences are small and not consistent.

The standard error of the experiment was determined from the deviations of the individual determinations from the means presented in table 1 and was calculated by the usual formula $\sqrt{\frac{\Sigma d^2}{n-1}}$. The standard error for a single determination of total carbohydrates is ±1.58 percent and of total nitrogen ±0.08 percent. The figures in the table are averages of 2, 4, and 6 determinations, and this fact must be considered wherever the standard error is applied.

TABLE 1.—*Effect of time and frequency of cutting on average percentage (on dry basis) of carbohydrates and nitrogen in alfalfa roots and on average percentage of normal stand surviving at end of experiment*

Plot nos.	Time of [1]—					Period of growth after last cutting	Constituents of roots dug after indicated cutting or at indicated stage in—											
							1929						1930					
							Third cutting [2]		Fourth cutting		Fall dormant		Spring dormant		First cutting		Second cutting	
	First cutting	Second cutting	Third cutting	Fourth cutting	Fifth cutting		Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen
						Days	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1 and 16	Tenth bl.					130	44.9	1.99			[3] 44.5	[3] 2.35	34.4	2.40	38.5	1.82		
2 and 17																		
3 and 18	Tenth bl.	FB	FB	FB		0	44.9	1.99	40.4	2.20	40.4	2.20	35.0	2.25	39.2	1.76	39.8	1.56
8 and 23																		
13 and 28																		
4 and 19	FB	FB				80	44.9	1.99			[3] 44.5	[3] 2.35	33.8	2.48	40.8	1.94	41.6	1.50
5 and 20																		
6 and 21	FB	FB	Sept. 1			40	44.9	1.99			44.5	2.20	30.4	2.14	42.9	1.88	40.1	1.72
7 and 22																		
9 and 24	FB	FB	Sept. 15			25	44.9	1.99			41.7	1.85	38.4	2.12	43.3	1.90	42.1	1.56
10 and 25																		
11 and 26	FB	FB	Oct. 1			10	44.9	1.99			38.9	2.09	34.3	2.23	43.4	1.82	43.1	1.48
12 and 27	B	B	B	B	B	0	44.9	1.59	45.9	1.75	40.1	1.85	34.9	1.92	36.3	1.53	36.4	1.20
14 and 29	FB	FB	Sept. 1	[4]	[4]	0	44.9	1.99	38.7	1.63	35.9	1.96	33.1	1.99	42.1	1.74	39.4	1.52
15 and 30	FB	Seed				35	44.9	1.99			44.5	2.35	36.0	2.44	43.4	1.91	44.1	1.45

Plot nos.	Constituents of roots dug after indicated cutting or at indicated stage—																				Stand 1932
	1930								1931										1932		
	Third cutting		Fourth cutting		Fifth cutting		Fall dormant		Spring dormant		Third cutting		Fourth cutting		Fifth cutting		Fall dormant		Spring dormant		
	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	Carbohydrates	Nitrogen	
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1 and 16							37.2	1.89	27.0	2.22							34.4	1.92	27.3	2.54	39.5
2 and 17																					
3 and 18																					
8 and 23	39.2	1.41	41.2	1.72			35.7	1.83	28.2	1.95	33.2	1.26	38.2	1.52			35.2	1.61	26.7	2.13	27.3
13 and 28																					
4 and 19							36.7	1.88	29.3	2.13							38.9	1.94	27.4	2.50	48.5
5 and 20																					
6 and 21																					
7 and 22	34.6	1.46					35.8	1.73	29.7	1.81	34.5	1.41					37.3	1.72	28.8	2.24	50.5
9 and 24																					
10 and 25	37.4	1.73					37.4	1.57	30.6	1.74	32.9	1.51					34.6	1.62	27.3	2.18	44.5
11 and 26	39.4	1.83					33.7	1.95	27.0	1.83	34.6	1.55					34.4	1.51	28.5	2.23	50.0
12 and 27	38.2	1.43	37.0	1.25	37.9	1.15	35.7	1.71	29.5	1.79	34.8	1.38	32.9	1.19	33.2	1.47	36.2	1.50	26.4	2.19	18.0
14 and 29	33.4	1.40					28.1	1.35	25.4	1.67	33.0	1.39					29.1	1.49	25.8	2.06	16.0
15 and 30							37.6	1.84	29.2	2.01							38.8	1.88	28.0	2.59	62.0

[1] Significance of abbreviations: Bl., bloom; B, bud stage; FB, full-bloom stage; Seed, seed stage. Leaders indicate that no further cuttings were made.
[2] Average of 6 samples taken at random at beginning of experiment, except for plots 12 and 27.
[3] Average of 4 samples from plots that had received similar treatment previously.
[4] Clipped at 10-day intervals after last cutting.

TABLE 2.—*Weekly trend of percentage of carbohydrates and nitrogen (on dry basis) in alfalfa roots, 1931 and 1932*

Date sampled	Plot 1				Plot 2				Plot 3				Plot 4				Plot 5			
	Date cut	Stage of growth at sampling	Constituents of roots		Date cut	Stage of growth at sampling	Constituents of roots		Date cut	Stage of growth at sampling	Constituents of roots		Date cut	Stage of growth at sampling	Constituents of roots		Date cut	Stage of growth at sampling	Constituents of roots	
			Carbohydrates	Nitrogen			Carbohydrates	Nitrogen			Carbohydrates	Nitrogen			Carbohydrates	Nitrogen			Carbohydrates	Nitrogen
			Per cent	*Per cent*			*Per cent*	*Per cent*			*Per cent*	*Per cent*			*Per cent*	*Per cent*			*Per cent*	*Per cent*
1931																				
May 28					May 28	B	36.5	1.41	May 28	B	35.0	1.32	May 28	B	36.1	1.37	May 28	B	36.3	1.49
June 4							32.8	1.52												
June 11							26.6	1.46												
June 18							23.3	1.27												
June 25						[1] 14	29.9	1.16	June 25	B	28.2	1.66	June 25	B	28.4	1 16	June 25	B	29.8	1.24
July 2						[1] 17	33.6	1.49		[1] 2	24.7	1.18								
July 9					July 9	FB	37.7	1.43		[1] 8	25.0	1.05								
July 16										[1] 10	27.9	1.18								
July 24										[1] 11	34.8	1.27	July 24	B	35.8	1.32	July 24	B	36.4	1.41
July 30										[1] 13	36.1	1.40		[1] 2	33.9	1.39				
Aug. 3									Aug. 3	FB	38.7	1.40								
Aug. 6														[1] 5	31.7	1.31				
Aug. 13														[1] 12	28.1	1.19				
Aug. 20														[1] 17	31.8	1.04				
Aug. 24					Aug. 24	FB	36.9	1.32												
Aug. 27														[1] 22	34.0	1.25				
Aug. 29																	Aug. 29	B	36.4	1.29
Sept. 3														[1] 23	37.6	1.35		[1] 2	34.4	1.29
Sept. 10														[1] 25	38.4	1.51		[1] 4	31.7	1.31
Sept. 14													Sept. 14	FB	39.7	1.53				
Sept. 17																		[1] 8	29.9	1.07
Sept. 24									Sept. 24	FB	35.8	1.57						[1] 13	31.0	1.08
Oct. 1																		[1] 15	36.3	1.21
Oct. 8																		[1] 17	38.2	1.37
Oct. 15					Oct. 15	FB	38.8	1.48		[1] D 8	35.0	1.29		[1] D 13	38.2	1.43		[1] 17	39.0	1.45
Oct. 28						D	36.4	1.45		D	39.8	1.71		D	39.6	1.66		[1] D17	39.2	1.61
Dec. 1						D	35.2	1.41										D	35.7	1.50
1932																				
Feb. 25		[2] D	28.7	2.68		D	28.9	2.66		D	29.0	2.60		D	29.0	2.69		D	29.3	2.77
Apr. 2		[1] 2	28.1	2.08																
Apr. 9		[1] 5	26.3	1.66																
Apr. 16		[1] 9	24.3	1.46																

Apr. 23			[1] 12	23.6	1.45																
Apr. 30			[1] 16	23.0	1.57																
May 16			[1] 20	26.6	1.72																
May 21				28.9	1.81	May 21	B	30.4	2.00	May 21	B	28.9	1.83	May 21	B	27.8	1.84	May 21	B	29.4	1.74
May 28			[1] 24	30.8	1.39		[1] 3	26.1	2.00												
June 4			[1] 24	33.3	2.04		[1] 7	20.6	1.83												
June 11	June 11	FB	33.4	2.05			[1] 14	20.1	1.57												
June 18							[1] 16	24.9	1.73												
June 21							B	29.8	1.98	June 21	B	30.6	1.70	June 21	B	29.8	1.59	June 21	B	29.4	1.72
June 25											[1] 3	28.3	1.80								
July 2											[1] 5	23.8	1.75								
July 6						July 6	FB	34.4	1.92												
July 9											[1] 10	23.0	1.60								
July 16	July 16	FB	34.4	2.02							[1] 16	27.5	1.66								
July 23											B	32.0	1.76	July 23	B	30.3	1.61	July 23	B		
July 30																					
Aug. 3										Aug 3	FB	34.4	2.02								
Aug. 6																24.1	[1] 60				
Aug. 15						Aug. 15	FB								B			Aug. 15	B	28.1	1.50
Aug. 20															[1] 18	28.6	1.47		[1] 3	25.2	1.53
Aug. 23	Aug. 23	FB	31.5	1.81										Aug. 27	FB	31.1	1.68		[1] 4	24.6	1.37
Aug. 27																26.3	1.68		[1] 6	25.0	1.37
Sept. 3																24.4	1.54		[1] 8	27.8	1.45
Sept. 10										Sept. 10	FB	32.9	1.83			25.0	1.41			29.7	1.60
Sept. 17												31.5	1.86			28.1	1.56		[1] 10	33.1	1.82
Sept. 24												28.9	1.68								
Sept. 28						Sept. 28	FB	33.3	1.91												
Oct. 1											[1] 3	29.8	1.61		[1] 8	32.3	1.68		[1] 11	32.7	1.89
Oct. 5	Oct. 5	FB	32.9	1.73			[1] 2	29.3	1.93		[1] 3	29.4	1.55		[1] 8	32.2	1.69		[1] 12	33.4	1.93
Oct. 8											[1] 3	30.3	1.61						[1] 12	33.4	1.90
Oct. 15											[1] 3	32.0	1.65						[1] 12	35.7	2.09
Oct. 22											[1] 3	35.8	1.82						[1] 12	36.8	2.03
Oct. 29											[1] 3	34.9	1.74						[1] 12	36.9	2.12
Nov. 5											[1] 3	34.4	1.84						[1] 12	37.3	2.13
Nov. 12											[1] 3	35.7	1.83						[1] 12	36.4	2.14
Nov. 21		D	34.1	2.10			[1] 2	31.5	1.91		[1] 3	35.5	1.90		[1] 8	35.2	2.08		[1] 12	35.8	2.21
Nov. 21	Nov. 21[3]	D	32.3	1.93	Nov. 21	D	29.7	1.80	Nov. 21	D	29.7	1.80	Nov. 21	D	32.5	1.81	Nov. 21	D	33.3	1.98	

[1] Inches.
[2] Root samples were taken for analysis at each stage of growth indicated. Significance of abbreviations: B, bud stage; FB, full-bloom stage; D, dormant.
[3] Samples of roots were taken from the cut portion (designated *a*) of each plot at the end of the fall dormant period.

Data from this experiment relating to stand have been presented in another paper (*8*), but a summary is given in table 1. It is apparent that, in general, late cuttings, which leave only a short fall growing period before winter, reduced the stands materially below those in which the growing period after the last cutting was longer. The data in table 1 show good agreement between stand and root reserves, except for plots 11 and 26, in which all cuttings were made at full bloom or later, when the root reserves were high.

EXPERIMENT 2

The data from the second experiment, which was conducted in 1931 and 1932, are given in table 2. Very similar results were secured in the two seasons. The data for 1932 are presented graphically in figure 1, the curves having been drawn freehand to represent the

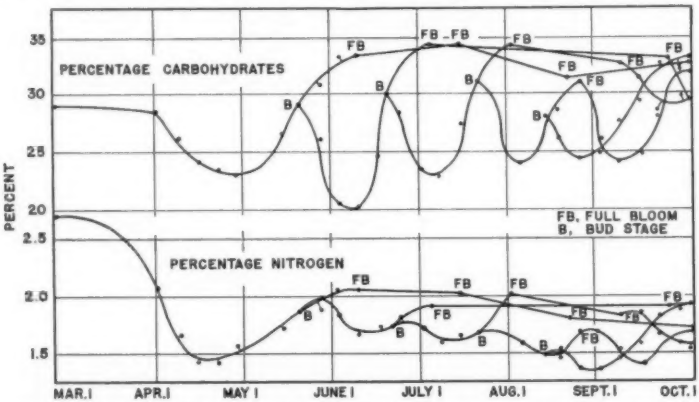

FIGURE 1.—Trend of total carbohydrates and nitrogen during growing season of 1932 as affected by different cutting treatments. Curves were drawn freehand from data in table 2. Dots indicate date of sampling. Dots not intersected by curves are connected by lines to their respective curves.

best fit. It will be noted that when growth starts in the spring and after each cutting there is a rapid decline of total carbohydrates and of nitrogen in the roots. However, the nitrogen curve for a short time after each cutting shows an increase. Probably at that time relatively more carbohydrate than nitrogen is used and hence there is an increase in nitrogen on a percentage basis. This condition is soon changed, and the curve starts down, following closely that of the carbohydrates. Under normal growing conditions, the carbohydrate and nitrogen curves reach a minimum about 20 days after cutting, after which there is a rapid increase, reaching a maximum when the plants are in full bloom. The point of minimum storage appears to depend on the amount of plant growth or probably leaf surface and rate of growth. These relations no doubt depend very materially on temperature and probably on other factors.

DISCUSSION

The effect of the length of the growing period after the last cutting on the accumulation of carbohydrates during the fall dormant period, especially the effect of removing the aftermath at the time growth ceased (Oct. 5), is shown in figure 2. The effect can best be seen by comparing the *b* curves for the different plots and by comparing the *a* and *b* subdivisions for each plot. With respect to the former comparison, it will be noted that the carbohydrate content of the roots

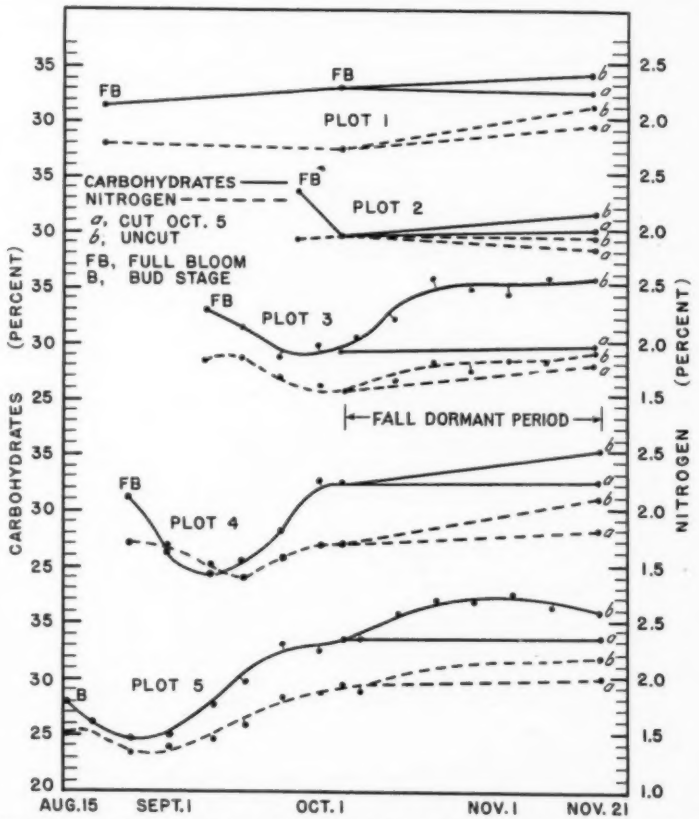

FIGURE 2.—Effect of length of growing period after last cutting in fall and of remaining aftermath on storage of total carbohydrates and nitrogen in roots during fall dormant period, 1932.

at the last sampling date of the season (Nov. 21) was substantially the same for all plots except plot 2, on which it was low. This no doubt is explained by the fact that on this plot the last cutting took place a short period before growth ceased, and the aftermath depleted these reserves but was not sufficient to restore them. On the contrary, the length of the growing period in plots 3, 4, and 5 was sufficient to restore the reserves before November 21. On plot 1

the last cutting coincided with the end of the growing period, hence there was no aftermath and no depletion of reserves.

It will also be noted that in all cases both the carbohydrate and the nitrogen content of the roots on the *b* division, in which the aftermath was not cut until November 21, was moderately greater than on the *a* division of the same plots, on which the aftermath was cut as soon as growth ceased (Oct. 5). These comparisons and the shape of the carbohydrate and nitrogen curves after the last cutting, taken in conjunction with the form of the curves shown in figure 1, seem to afford rather conclusive evidence that the amount of growth which takes place after the last regular cutting has a material bearing on the organic reserves stored in the roots.

It seems that in some cases the last cutting may be too early for a maximum accumulation of reserves. This is indicated by the data from plot 5 in 1931 (table 2), in which the fourth and last cutting was made August 29. On this date the carbohydrate content was 36.4 percent. This increased to a maximum of 39.2 percent on October 28 and afterward decreased to 35.7 percent on December 1. The growing period after the last cutting was long this season and the new growth matured before the beginning of the fall dormant period and a second new growth started from the crowns. No doubt the carbohydrates were decreased as a result. There was no material decrease in 1932 after the date of maximum storage, but in this case the season was shorter and growth ceased about October 5 instead of October 28. The data indicate that the growing period after the last cutting should be only long enough to permit 8 to 10 inches of growth.

Observations of spring growth in 1932 and 1933 indicated some benefit from allowing the aftermath to remain through the winter, as compared with removing it in the early or late fall. Growth started earlier and continued more vigorously throughout the first and part of the second crop. This suggestion is supported by the data in table 3, which shows the effect of these treatments on yield. As compared with *b* plots, in which the aftermath remained until it was killed by frost, the lowest yields were recorded in every case for *a* plots, in which the aftermath was removed as soon as growth ceased; the *b* plots, in turn, in every case but one, produced lower yields than the *c* plots, on which the aftermath remained until spring. Leaving the aftermath on until it was frozen resulted in an average increase of 16.2 percent, and leaving it on until spring resulted in a further increase of 13.2 percent. However, approximately 10 percent of the latter increase was due to the old growth harvested with the new crop, which, when subtracted from that increase (13.2 percent) leaves 3.2 percent due to winter protection. In calculating these averages, plot 1 was omitted because the growth that was left on was equal to a full crop and in farm practice would have been removed as a fourth cutting, as was done on the *a* and *b* divisions; and plot 2 was omitted because there was no aftermath.

The data in figure 1 suggest that the percentage of total carbohydrates at comparable stages of growth during midsummer is lower than in the earlier or the later part of the season when the temperature is lower. This would be expected from the known relations between temperature and the storage of carbohydrates, as pointed out by Miller (*11, p. 451*), and by Nightingale (*14*).

TABLE 3.—*Effect of previous treatments on yield of alfalfa hay in first cutting*

Plot no.	Previous year's treatments						Average of the first cutting, 1932 and 1933	
	Stage of cutting				Fall [1]	Average growth period after last cutting	Height of plants at first cutting	Air-dried hay per acre at first cutting
	1	2	3	4				
						Days	*Inches*	*Pounds*
1	FB	FB	FB	FB	*a*	0	14	1,904
	FB	FB	FB	FB	*b*	0	16	2,287
	FB	FB	FB	(2)	*c*	47	18	2,887
2	B	FB	FB	FB	*a*	7	14	1,961
	B	FB	FB	FB	*b*	7	14	2,032
	B	FB	FB	FB	*c*	7	14	1,815
3	B	B	FB	FB	*a*	22	14	2,017
	B	B	FB	FB	*b*	22	15	2,317
	B	B	FB	FB	*c*	22	17	2,385
4	B	B	B	FB	*a*	38	14	2,096
	B	B	B	FB	*b*	38	16	2,478
	B	B	B	FB	*c*	38	17	3,007
5	B	B	B	B	*a*	50	15	2,220
	B	B	B	B	*b*	50	17	2,565
	B	B	B	B	*c*	50	17	2,943

[1] *a*, Top growth removed at the beginning of the fall dormant period; *b*, top growth removed after being killed by freezing; *c*, top growth left on for winter protection and removed with the first cutting.
[2] Fourth crop not cut; left for winter protection.

Tables 1 and 2 show a decided decrease in the amount of total carbohydrates at similar stages of development, from year to year. This is probably the result of an increase in the fibrous tissues as the alfalfa roots become older, resulting in a percentage decrease in other constituents. The relation here, so far as nitrogen is concerned, is not so obvious, probably because of the greater effect of stage of growth on nitrogen content.

SUMMARY AND CONCLUSIONS

Twenty years of experimental studies relating to the time and frequency of cutting alfalfa at the Kansas Agricultural Experiment Station have gradually indicated that the fall of the year is the critical period insofar as cutting practices are related to organic root reserves and permanence of stand. Experiments were conducted from 1929 to 1932 in a study of the trend of nitrogen and carbohydrate reserves as affected by various cutting practices during the year, especially in the late fall, and the effect of these reserves on plant survival.

It was found that when growth starts in the spring, and after each cutting, there is a rapid decline of total carbohydrates and of nitrogen until a minimum is reached, after which there is a rapid increase. During the seasons studied, the minimum carbohydrate and nitrogen content was reached about 20 days after cutting. The maximum accumulation apparently occurred when the plants were about in full bloom.

Early and frequent cutting, as in the bud stage, appeared to result in a lower carbohydrate and nitrogen content of the roots when winter arrived, and, conversely, infrequent cutting resulted in a higher content of those reserves. The differences, however, were neither large nor entirely consistent. Clipping every 10 days after the last cutting greatly reduced the nitrogen and carbohydrate reserves and also the stand.

Data were secured which seem to afford rather conclusive evidence that the amount of growth which takes place after the last regular cutting has a material bearing on the organic reserves stored in the roots before winter. If this amount is small the reserves are depleted and there is no opportunity to restore them. It appears that there must be at least 8 to 10 inches of growth to permit maximum storage.

Removing the aftermath when growth ceased in the fall resulted in a lower carbohydrate and nitrogen content than was obtained by leaving this aftermath on the plots.

Permitting the aftermath to remain during the winter appeared to result in a more vigorous growth and an increased yield of the first cutting the following spring.

The percentage of total carbohydrates in alfalfa roots at similar stages of growth decreased as the stand became older.

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YIELD AND CHEMICAL COMPOSITION OF CERTAIN SPECIES OF GRASS [1]

By J. G. ARCHIBALD, *assistant research professor of chemistry*, and E. BENNETT, *research assistant in chemistry, Massachusetts Agricultural Experiment Station* [2]

INTRODUCTION

A search of the literature a few years ago disclosed a scarcity of information on the chemical composition of individual species of grass indigenous to the northeastern part of the United States. Such information would be a valuable adjunct in solving the problem of pasture management, which has been receiving a greatly increased amount of attention in the past 5 years. Accordingly a project was initiated in 1930 for a chemical study of some of the common grasses grown as pure or practically pure stands of the individual species. This paper reports the results of 3 years' work.

EXPERIMENTAL PLOTS AND PROCEDURE

The tract of land chosen for the grass plots is located at the top of a low ridge on the experiment station farm, uniformly level from north to south, but with a slight slope to the west. The soil type is classified as Merrimac fine sandy loam. The surface soil varies in depth from 6 to 12 inches, and is underlain by an orange-brown sandy subsoil grading into loose gravel at from 12 to 24 inches below the ground surface. Mechanical and chemical analyses of the soil are given in table 1.

TABLE 1.—*Results of soil analyses on a basis of air-dry soil* [1] [2]

Profile	Fine soil (1 mm or less)	Organic and volatile matter	Total nitrogen	Total phosphorus	Total potassium	Total calcium	Available phosphorus	pH
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*P. p. m*	
Surface soil	92. 17	5. 06	0. 139	0. 183	2. 01	1. 43	154	6. 05
Subsoil	99. 33	2. 63	. 044	. 030	1. 85	1. 44	58	5. 50

[1] Samples taken Sept. 20, 1932.

[2] All determinations except available phosphorus were made according to the following: ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS. . . . Ed. 3, 593 pp., illus. Washington, D. C. 1930. Available phosphorus was determined by Truog's method.

Previous to 1930 the land had been devoted for years to variety and yield tests on corn or corn and soybeans, and the fertilizer treatment had been uniform for at least 10 years.

[1] Received for publication Oct. 19, 1934; issued June 1935. Contribution no. 205 of the Massachusetts Agricultural Experiment Station.

[2] Grateful acknowledgment is made of the services of A. F. Spelman and J. W. Kuzmeski, who made the determinations of crude fiber and ether extract under the direction of Phillip H. Smith, chief chemist of the feed inspection laboratory of this station, and also of the services of H. R. De Rose, who made the potassium determinations under the direction of H. D. Haskins, chief chemist of the fertilizer control laboratory of this station.

The species chosen for the investigation were:

Canada bluegrass (*Poa compressa* L.).
Kentucky bluegrass (*Poa pratensis* L.).
Orchard grass (*Dactylis glomerata* L.).
Redtop (*Agrostis alba* L.).
Rhode Island bent (*Agrostis capillaris* L.).
Timothy (*Phleum pratense* L.).
Sheep fescue (*Festuca ovina* L.).
White Dutch clover (*Trifolium repens* L.).

The series was replicated once, making a total of 16 plots. Each plot was 3½ feet wide by 62 feet long, and had an area of approximately one two-hundredth of an acre. Paths 1 foot wide were maintained between the plots with a border 3 feet wide on the margins of the tract. Fertilizer was not applied, as it was desired to ascertain first the composition of the various species grown without fertilizer other than that residual in the soil. The plots were seeded in the late summer of 1930 without a nurse crop, and kept free from weeds by hand work. A reasonable degree of success was attained in keeping the individual species pure. The attempt to secure a pure stand of Canada bluegrass was reluctantly abandoned after three reseedings; competition from other species invariably crowded it out.

Sampling of the plots was done by means of a lawn mower with grass catcher attached. One swath of the mower the entire length of each of the duplicate plots usually provided a sufficient sample; in any case an identical area of the duplicates was always sampled. Occasionally, where patches of other species or of weeds had crept in, the sampling was done by the quadrat method, so that such areas could be avoided. The samples were taken whenever the grass reached a height of 3 to 4 inches, so that time intervals between samplings varied with species and season of the year. Whenever possible a minimum of one sample a month from each species was taken for detailed analysis in each of the 5 months from May through September. Wherever rate of growth necessitated taking more than one sample a month, yield and moisture content only were determined on the additional samples. The entire plot was always mowed immediately after sampling.

Samples were brought to the laboratory and weighed immediately after cutting. After suitable portions had been weighed out for moisture determination, the bulk of the sample was air-dried, then oven-dried at 60° to 70° C., ground in a Wiley mill, and bottled for analysis. The determinations made were moisture, total nitrogen, crude fiber, ether extract, total ash, acid-soluble ash, calcium, phosphorus, magnesium, and potassium. All analyses excepting those for calcium, phosphorus, and magnesium were made according to the official methods of the Association of Official Agricultural Chemists.[3] Calcium and magnesium were determined by a modification of McCrudden's [4] method, and phosphorus by the colorimetric method of Fiske and Subbarow.[5]

[3] Association of Official Agricultural Chemists. See footnote 2, table 1.

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RAINFALL AND TEMPERATURE

A summary of weather conditions during the growing seasons of 1931, 1932, and 1933 appears in table 2.

TABLE 2.—*Rainfall and temperature at Amherst, Mass., during the growing seasons of 1931–33*

Year	Rainfall						Temperature					
	April	May	June	July	August	September	April	May	June	July	August	September
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*
1931	2.95	7.44	4.24	3.87	6.57	2.50	46.7	58.1	66.7	73.1	69.6	64.8
1932	2.33	1.67	2.62	3.83	2.67	3.96	44.4	57.9	62.9	68.9	70.5	62.5
1933	5.03	1.69	3.68	2.25	6.63	[1] 12.34	45.3	60.5	68.3	72.3	69.3	62.7
Average	3.44	3.60	3.51	3.32	5.29	3.23	45.5	58.8	66.0	71.4	69.8	63.3
Normal (40-year average)	3.27	3.63	3.54	4.33	4.24	3.79	45.8	56.8	65.4	70.6	68.4	61.6

[1] Not included in the average because the small number of samples taken in September 1933 were taken early in the month, before these abnormally heavy rains fell.

Except for the month of April the average temperature in all three seasons was consistently above the 40-year normal established for Amherst. Rainfall varied within wide limits, but was consistently below normal in July of all 3 years, which was compensated somewhat by copious rains in August of 1931 and 1933.

PRESENTATION AND DISCUSSION OF RESULTS

Summarized results of the yield and composition of the various grasses appear in table 3.

TABLE 3.—*Summary of results of yields and analyses of the various grass species, seasons of 1931–33*

Species of grass	Samples	Relative yield of dry matter [1]	Moisture in the fresh grass	Analyses on a dry-matter basis								
				Nitrogen	Crude fiber	Ether extract	Total ash	Acid-soluble ash	Calcium	Phosphorus	Magnesium	Potassium
	Number	*Pounds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Kentucky bluegrass	10	92	68.59	2.32	25.31	3.37	9.82	5.56	0.49	0.38	0.18	2.13
Orchard grass	14	99	75.73	2.66	23.77	4.67	12.99	9.27	.60	.68	.29	3.51
Redtop	12	104	71.99	2.49	23.32	4.10	10.79	6.99	.62	.35	.21	2.62
Rhode Island bent	15	81	67.55	2.50	22.62	3.60	10.36	6.32	.75	.38	.19	2.23
Sheep fescue	15	100	65.26	2.09	28.98	3.19	8.39	4.93	.48	.33	.15	1.92
Timothy	12	91	71.68	2.34	21.23	3.96	8.74	6.16	.50	.36	.15	2.44
White Dutch clover	11	140	83.21	4.46	14.82	3.14	11.65	10.15	1.61	.45	.23	2.24

[1] Average of all 7 species=100; expressed in this way because actual yields would be of no significance. In certain months of the several seasons, due to the necessity of reseeding, stands of some of the species were either nonexistent or else so recently established that the growth was insufficient to sample.

Considerable differences are noted in the composition of the several species. Taking the various components in the order in which they appear in table 3, the following points are worthy of mention:

(1) The harsh, wiry texture of sheep fescue is reflected in the lowest moisture content of the group.

(2) There was a close correlation between the nitrogen content of the dry matter and the moisture content of the fresh grass, the ratio for all six grasses being in the neighborhood of 1:30. Unpublished work by the authors and results of other investigators have shown that most of the nitrogen is in the form of true protein.

It will be noted that the nitrogen content of Kentucky bluegrass is somewhat lower, both in actual amount and relative to the other grasses studied, than has been generally reported in the literature. Since this relatively low nitrogen content occurred in 7 of the 10 samples of bluegrass some other explanation than the possibility of analytical error must be sought.

It may be that the soil in question is not a type on which bluegrass thrives well. It has been observed in the course of the work that it was harder to obtain a good stand of bluegrass than of some of the other grasses, and that the bluegrass plots never looked as thrifty as did the majority of the others. It is also possible that the bluegrass did not utilize the residual nitrogen of the unfertilized soil as well as some of the other species were able to; that it is at its best when the level of fertility is relatively high. This suggestion is borne out by data from these same plots for the year 1934. An 8–6–6 fertilizer was applied in the spring of 1934 at the rate of 500 pounds per acre, with the result that the blue grass samples for that year showed a much higher nitrogen content than for the 3 years here reported, the average being 3.51 percent as contrasted with 2.32 percent. This very considerable increase, for the time being, places the bluegrass second on the list in nitrogen content as an apparent result of fertilizer application.

(3) It is of interest to note the correlation between the percentage of crude fiber and the toughness of the grass as determined by breaking strength. Beaumont, Stitt, and Snell [6] of this station report the following breaking strengths for some common grasses expressed in grams per millimeter of perimeter (average of 50 determinations): Timothy, 58.6; redtop, 52.9; Kentucky bluegrass, 92.6; and red fescue, 147.9.

Except that the timothy had a slightly higher breaking strength than the redtop, these results correlate closely with the amounts of crude fiber reported above. Beaumont concludes that "other factors being favorable, toughness may be a deciding factor in palatability."

(4) The low value for ether extract in white clover is believed to be due to a lower content of wax in this species. Chibnall et al.[7] have shown that orchard grass has a wax content of 1.20 percent of the dry matter, while the wax content of alfalfa is only 0.35 percent on the same basis. It seems reasonable to assume, therefore, that

[6] BEAUMONT, A. B., STITT, R. E., and SNELL, R. S., SOME FACTORS AFFECTING THE PALATABILITY OF PASTURE PLANTS, Jour. Amer. Soc. Agron. 25: 123–128. 1933.

[7] POLLARD, A., CHIBNALL, A. C., and PIPER, S. H. THE WAX CONSTITUENTS OF FORAGE GRASSES. I. COCKSFOOT AND PERENNIAL RYEGRASS. Biochem. Jour. 25: 2111–2122. 1931.
CHIBNALL, A. C., WILLIAMS, E. F., LATNER, A. L., and PIPER, S. H. THE ISOLATION OF N-TRIACONTANOL FROM LUCERNE WAX. Biochem. Jour. 27: 1885–1888. 1933.

legumes as a class contain less wax than do grasses, an assumption borne out by superficial observation. Orchard grass, which Chibnall found to contain a relatively large amount of wax, had the highest content of ether extract in the present experiments.

(5) The acid-soluble ash of white clover constituted over 87 percent of the total ash, a proportion much higher than for any of the grasses. Orchard grass was the highest of the grasses in proportion of soluble ash in the total ash (over 71 percent), although timothy was close to it (70.5 percent). Some of the total ash was probably extraneous silica, due to adherent dust on samples taken in dry times or to spattering of soil onto the leaves during heavy rains; but since the clover with its pubescent leaves had an equal opportunity with the rest to become so contaminated, and yet showed such a high percentage of soluble ash in the total, it is believed that the amount of such extraneous material was relatively small in any case.

(6) True to its legume characteristics, the white clover had a very high content of calcium. Of the grasses the two members of the bent family, redtop and Rhode Island bent, were the highest, the latter outstandingly so. The ratio of calcium to phosphorus in these two (1.8:1 and 2.9:1, respectively) is wellnigh ideal from a nutritional standpoint. In this respect the white clover is probably too high (3.6:1), while the orchard grass is low (0.9:1)—another good reason for a mixture of grasses and legumes if optimum grazing conditions are to be approximated. Sheep fescue, Kentucky bluegrass, and timothy were all in the same class as regards both calcium content and the calcium-phosphorus ratio.

(7) The outstanding feature of the values for phosphorus was the high content of it in orchard grass. This high value was consistent through all three seasons, except at the beginning of each season, when the value was just as consistently low. It is associated with relatively high average values for most of the other constituents determined. The form in which this unusual amount of phosphorus exists in the plant and its significance from a nutritional standpoint would be an interesting subject for investigation.

(8) The values for magnesium were quite uniformly distributed through a range from 0.29 percent in orchard grass to 0.15 percent in timothy and sheep fescue.

(9) Orchard grass was much higher in potassium than any of the others, the clover occupying an intermediate position, while the fescue was at the foot again.

SUMMARY

Considering the results as a whole, the outstanding features of the investigation are the high rank of white Dutch clover in almost every respect; the high soluble ash and phosphorus content of orchard grass; the high calcium content of Rhode Island bent; the low rank of sheep fescue in every respect except yield; and the rather low rank of Kentucky bluegrass.

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